Environmental Research Consulting

Final Report

Bio-economic Modeling of Oil Spills from Tanker/Freighter Groundings on Rock Pinnacles in San Francisco Bay

Volume II of VII
Spill Volume Report

Prepared For:
Applied Science Associates
70 Dean Knauss Drive
Narragansett, RI 02882

Prepared By:
Dagmar Schmidt Etkin, Ph.D.
Environmental Research Consulting
750 Main Street
Winchester, MA 01890

And

Keith Michel
Herbert Engineering Corp.
2417 Mariner Square Loop, Suite 125
Alameda, CA 94501

Under Subcontract No.: 2001-038-01
US Army Corps of Engineers, Sacramento District
Oil Spill Analysis and Modeling (DACW07-01-C-0018)

May 2003

Table of Contents

Vessel Oil Spill Scenario Development For Tanker/Freighter Groundings on San Francisco Bay Rock Pinnacles

Summary

The first task in the San Francisco Rocks Removal Bio-Economic Oil Spill Modeling Study was to determine the appropriate oil spill scenarios for the 20th percentile, 50th percentile, and 95th percentile oil spills for four oil types.

The spill size for the "20th percentile spill" was defined as the spill size that was larger than 20% of all spills, but smaller than 80% of all spills. Likewise, the "50th percentile spill" was defined as the median spill or the spill size that was larger than 50% of all spills, but smaller than the other 50% of spills. And finally, the "95th percentile spill" was defined as the spill size that was larger than 95% of all spills and smaller than only 5% of all spills.

Two basic approaches were employed and compared in the development of the 20th percentile, 50th percentile, and 95th percentile oil spill scenarios for the tanker and freighter vessel groundings in San Francisco Bay:

- Examination of historical oil spill data for San Francisco Bay area for distribution of spill sizes; and
- Probabilistic modeling of likely oil spill scenarios based on actual vessel traffic in San Francisco Bay and the likely spill sizes for groundings from those vessels.

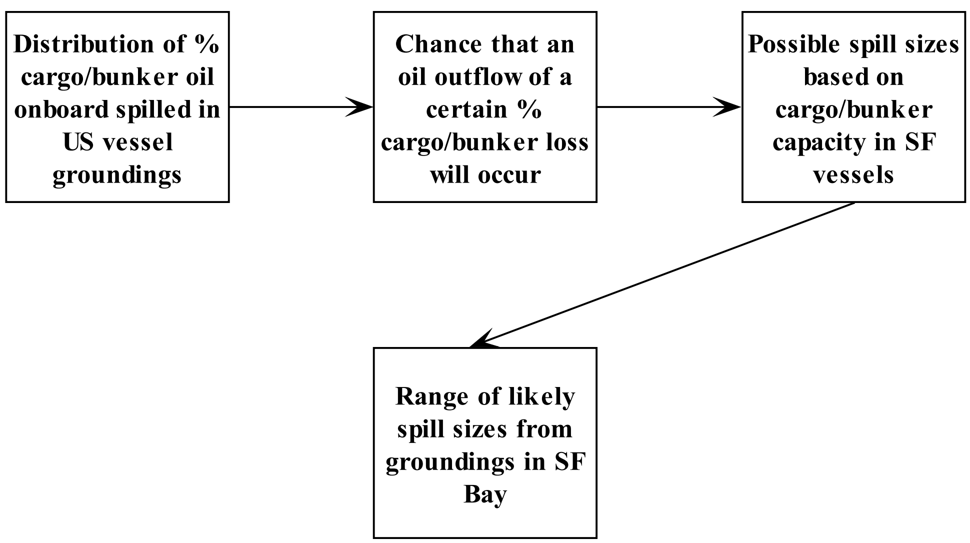
The first approach was found to give incomplete information due to the lack of sufficient data on groundings in San Francisco Bay. There were not enough grounding incidents to form the basis of any analysis.

The second approach gave a more robust analysis of the types of spills that might be expected in San Francisco Bay based on the vessel traffic that transits the shipping channels on an annual basis. This analysis provided the spill sizes for the oil spill scenarios for the different vessel types. The review of the vessel traffic also provided the necessary data to determine the appropriate oil types to use in the modeling of bio-economic impacts of these oil spills. *Only vessels with a draft deep enough to possibly impact the highest of the rock pinnacles were included.* Lower draft vessels would be expected to pass over the rock pinnacles with no chance of grounding.

The probabilistic modeling involved an analysis of actual grounding incident, including an estimation of the percentage of total cargo or bunkers spilled in each incident. This gave an assessment of the *percentage of cargo or bunkers likely to be lost in hypothetical*

grounding incidents – e.g., 8% of tanker spills due to groundings involve the loss of 15% of the oil on board, whereas in 69% of grounding-related tanker spills only 1% of the oil spills. Since different-sized tankers and freighters carry different amounts of oil (as cargo or bunker fuel), a wide range of spill sizes could be expected both due to the original oil capacity and the percentage of that capacity that actually spilled. An assessment of the spill sizes of grounding-related spills that could be expected from the actual vessels that transit San Francisco Bay was next conducted.

A cumulative probability distribution function was developed to show the relative percentage of spills of various sizes that would be expected to occur based on the vessel traffic and oil transport that occurs in San Francisco Bay. This distribution showed the size of oil spill that was larger than 20% of spills expected, i.e., the 20th percentile spill, as well as the 50th percentile, and 95th percentile spills for the three general vessel types – product tankers, crude tankers, and freighters.



It is important to note that this analysis did not provide an assessment of the actual risk of a grounding occurring or the probability that a spill would occur in the event of grounding on the San Francisco Bay rock pinnacles, but only an assessment of the sizes of spills that might be expected if a spill did occur. A brief analysis of the outcomes of groundings in US waters as well as the reduction in the incidence of grounding-related spillage due to double-hulls in tankers on an international basis is provided to give some perspective to the actual chance of spills occurring. This analysis is not meant to provide a comprehensive assessment of the probability of spillage in the event of grounding.

Three different data sets were used for modeling of the tanker and freighter grounding spill volume-scenarios: (1) US data only, (2) using international data, and (3) using international data with correction for future use of double-hull tankers. The international data set was adjusted to remove spills that were irrelevant to the circumstances in San

Francisco Bay, namely spills that involved catastrophic drift groundings in storms and other situations in which there was a complete loss of control of the vessel. In addition, one spill that involved excessive loss during salvage operations (the total outflow of which was included in spill volumes) was also eliminated in this adjusted analysis. A verification exercise was conducted to validate the use of actual data to develop spill size probability functions in these analyses.

The implication of future increases in the relative proportion of double hull tankers in transiting tanker fleets is discussed in as far as the potential decrease in spill volumes expected in future spill scenarios. Likewise, the impact of changes in bunker tank configurations on freighter grounding spills is also discussed.

The calculated oil spill volumes for each spill scenario were adjusted based on future tanker configurations that will reduce the expected oil outflow in the event of grounding accidents. The spill volumes for bunker spills from freighter groundings were not adjusted as the expected size of oil outflow is not likely to change significantly with changes in bunker tank configurations.

The final recommendations for spill volumes for the bio-economic modeling of spill scenarios for hard groundings on the rock pinnacles in San Francisco Bay are shown in the following table. These are based on international data, including correction for future use of double-hull tankers.

Recommended Oil Spill Scenarios For Vessel Groundings on Rock Pinnacles In San Francisco Bay			
Oil Type	**20th Percentile**	**50th Percentile**	**95th Percentile**
Gasoline (Product Tanker)	50,000 gallons	270,000 gallons	1,250,000 gallons
No. 2 Diesel (Product Tanker)	50,000 gallons	270,000 gallons	1,250,000 gallons
North Slope Crude (Crude Tanker)	100,000 gallons	600,000 gallons	3 million gallons
Heavy Fuel Oil (Freighter)	25,000 gallons	100,000 gallons	410,000 gallons

Two product tanker scenarios were selected for the bio-economic modeling because the two product types that are carried in the largest quantities in San Francisco Bay – gasoline and No. 2 diesel – would have very different impacts in the event of a spill. North Slope crude was selected as the crude oil type since it is the crude carried in the largest quantities in San Francisco Bay. Spillage of bunkers from tankers was not included in this analysis, as the probability of a grounding incident leading to oil spillage of bunker fuel in a modern tanker is very low.

Most diesel-powered ships burn heavy fuel oil (HFO), whereas steamships typically burn heavier residuals such as Bunker C. Nearly all international flag freighters employ diesel propulsion. Although a significant number of US-flag containerships are powered by steam, most of these vessels are more than 25 years of age. Replacement vessels will likely be diesel-powered. Therefore, heavy fuel oil was selected as the fuel for freighters.

1.0 Historical Oil Spill Data For San Francisco Bay Area

An analysis of oil spills from vessels over 300 GRT in the San Francisco Bay area during 1985-2000 shows a total of 182 reported incidents of at least 1 gallon spilled (Figure 1), with total spill volumes ranging from 4 gallons to over 13,000 gallons.

Over 97% of these spills occurred while the vessels were in dock or at anchor, usually while taking on fuel or loading or unloading petroleum cargo. Only five spills during the 1985-2000 time period were reported to occur while the vessel was in transit. These incidents are shown in the Table 1. The only one of these incidents that was specifically caused by grounding was the M/V Vitoria spill.

Figure 1

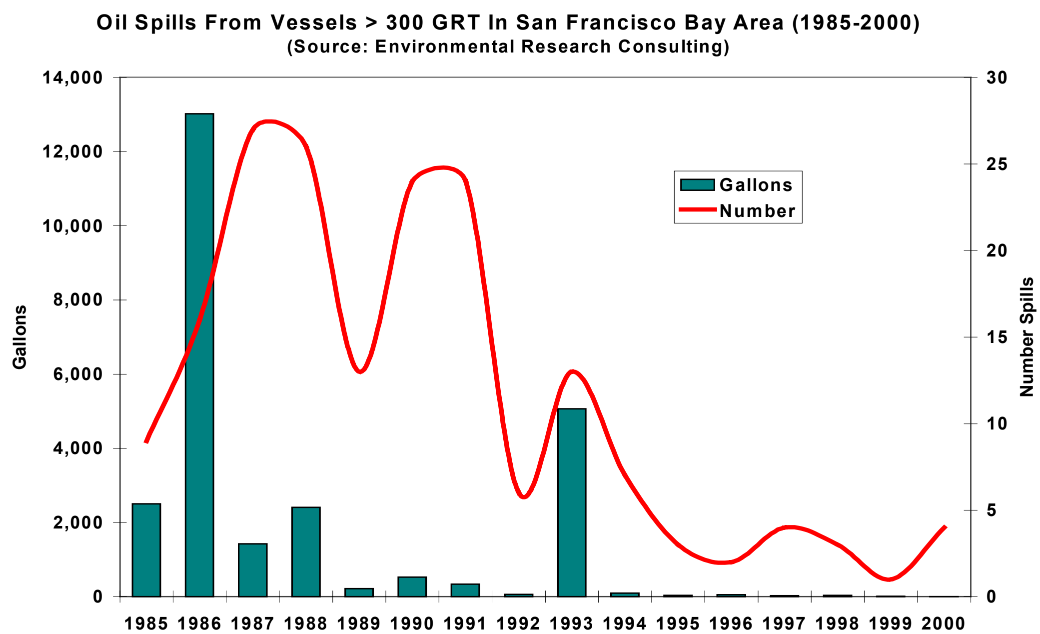


Table 1
In-Transit Oil Spills From Tankers, Barges, and Cargo Vessels (>300 GRT)
In San Francisco Bay Area 1985-2000

Date	Vessel Name	Vessel Type	GRT	DWT	Oil Type	Gallons Spilled
1/1/1988	Discovery Bay	Freight Ship	27,823	29,288	Diesel	1
1/2/1988	Chevron Louisiana	Tank Ship	16,941	39,789	Diesel	1
6/12/1990	Barge 51	Tank Barge	1,370	n/a	Diesel	252
7/4/1991	Vitoria[1]	Freight Ship	14,728	26,479	Lube	1
6/10/1997	Barge Bell 157	Freight Barge	945	n/a	Diesel	25

Source: Environmental Research Consulting Oil Spill Databases
[1]Caused by grounding.

Because there was such a small data set of spills that were in any way relevant to the current study – i.e., spills of vessels of at least 300 GRT that occurred while in transit – the use of these data was deemed inadequate for developing spill scenarios for potential spills in the San Francisco Bay area due to grounding on the rock pinnacles in question.

2.0 Development Of Likely Oil Spill Scenarios Based On Probabilistic Modeling

The second approach entailed developing a probability function based on actual vessel traffic in San Francisco Bay shipping channels. The first step was to examine the actual vessels that transit the San Francisco Bay shipping channels each year. A listing of all vessel transits through the shipping channels during the previous 12 months (August 2000 through July 2001) was obtained from the US Coast Guard Vessel Traffic Service (VTS) Operations, San Francisco. This list provided the following information for each of 6,205 vessel transits:

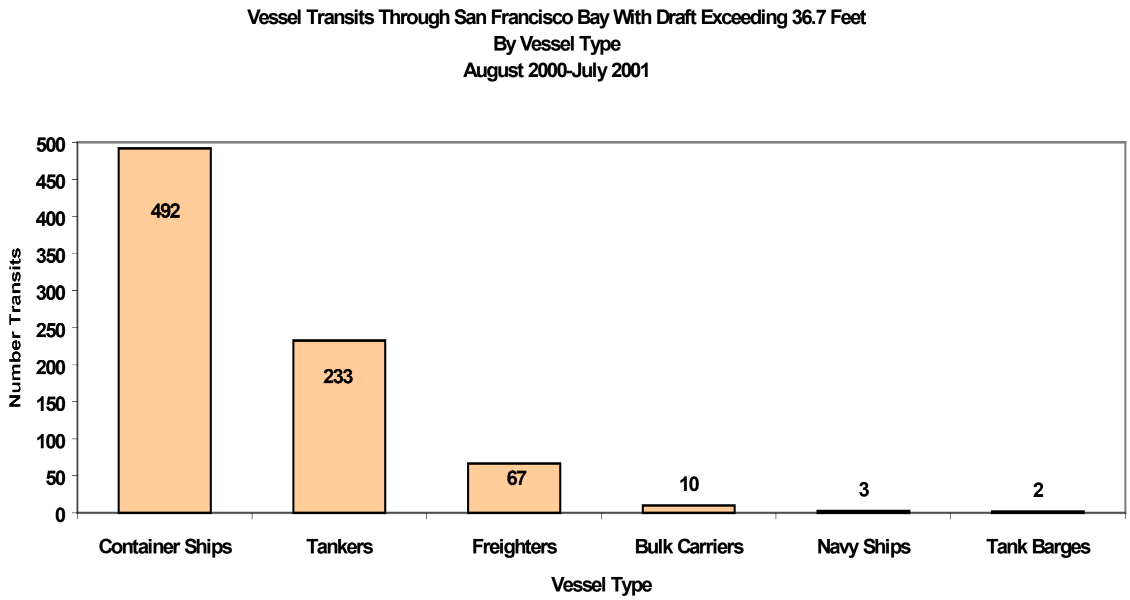
- Name and call number of the vessel;
- Vessel's draft for that transit;
- Vessel's deadweight tonnage (if available);
- Vessel's gross registered tonnage (if available);
- Vessel type (e.g., tank ship, container ship); and
- Direction of transit (seaward or into the bay).

Information on deadweight tonnage and gross registered tonnage for the vessels that was not available in the VTS list was obtained from Clarkson's Register of Shipping and Lloyd's Maritime Directory. The cargo and bunker fuel capacities for many of the vessels were also found in the Clarkson's Register. In cases where the vessel cargo and/or bunker fuel capacity was not available in the Clarkson's Register, the capacity was derived from a regression formula that described the relationship between deadweight tonnage (DWT) and bunker and/or cargo capacity in vessels with known DWT and cargo/fuel capacities.

US Geological Survey maps based on National Oceanic and Atmospheric Administration (NOAA) acoustical sounding survey data showed that the depth of the four rock pinnacles in San Francisco Bay ranged from 36.7 feet to 40.0 feet at mean lowest low water (MLLW). Vessel transits were broken down into vessel transits of greater than 36.7 feet and those less than this draft. It should be noted that in a number of cases the same vessel had a reduced draft during transits into or out of the bay depending on the amount of cargo on board. Only the transits that actually involved a draft depth of 36.7 feet were included in the deeper draft data set. This data set was then used for analysis as this represented the vessel transits for which there was a potential for grounding on the highest of the rock pinnacles.

Of the 807 vessel transits that exceeded the 36.7 -foot draft, nearly 61% were container vessel transits, 29% were laden tanker transits, 8% were freighter transits, and 1% were bulk carrier transits. Navy ships and barges accounted for 0.4% and 0.2% of transits, respectively. (See Figure 2.)

Figure 2



2.1 Tanker Spill Scenario Analysis

Product and crude tankers that transited San Francisco Bay shipping channels at least four times during the 12-month period of August 2000 through July 2001 are shown in the Table 2. These tankers account for nearly 66% of all the tanker transits.

Tanker transits were divided into size categories by deadweight tonnage (DWT) as shown in the following Figure 3. It was assumed that laden tankers are loaded to 80% of their capacity, and that the average quantity of bunkers on board equals 70% of the bunker tank capacity. The 80%-full cargo capacities and 70%-full bunker capacities of each DWT class were determined from vessel information in the Clarkson Register or derived from the regression equation in Figure 4. The bunker and cargo capacities for the different DWT classes are shown in Table 3. The annual tanker transits (with drafts over 36.7 feet) by cargo and bunker capacities are shown in Figures 5 and 6.

Table 2: Tankers With At Least Four Transits of San Francisco Bay With Draft of Over 36.7 feet During August 2000-July 2001								
# Transits >36.7-ft. draft[1]	**Tanker Name[1]**	**Hull [2]**	**DWT[2]**	**Avg. Draft (ft.)[2]**	**Bunker Capacity[2] (tonnes)**	**Fuel [2]**	**Cargo Capacity[2] (98% full) (tonnes)**	**Cargo[2]**
25	Chevron Mariner	DH	156,382	44.3	n/a	HFO	179,775	Crude
22	S/R North Slope	SS	176,405	38.2	5,216	n/a	189,201	Crude
20	Samuel Ginn	DH	156,835	43.8	4,712	HFO	179,775	Crude
18	S/R Benicia	SS	176,405	37.4	5,216	n/a	189,089	Crude
14	S/R Long Beach	SS	214,862	50.3	4,846	IFO	236,071	Crude
10	Chevron Mississippi	DH	71,360	40.6	2,354	n/a	77,868	Product
8	Polar Alaska	DB	191,460	43.6	8,146	IFO	209,981	Crude
6	Chevron Atlantic	DH	149,748	43.4	4,120	n/a	163,648	Crude
5	Chesapeake Trader	DB	50,685	38.8	2,289	HFO	52,000	Product
5	S/R Baytown	DB	58,686	39.9	1,794	HFO	72,000	Product
4	Chevron Employee Pride	DH	156,447	37.6	4,712	HFO	179,775	Crude
4	Chevron Washington	DH	39,167	37.9	1,821	n/a	42,768	Product
4	Condoleezza Rice	DH	135,829	36.7	4,706	n/a	159,291	Crude
4	Polar California	DB	127,003	39.1	8,146	IFO	205,800	Crude
4	Samuel L Cobb	DH	32,572	36.7	1,376	HFO	38,000	Product

[1]US Coast Guard Vessel Traffic Service Operations, San Francisco, California
[2]Clarkson Register, London, UK (DH = double hull; DB = double bottom; SS = single skin; DWT = deadweight tonnage)
n/a = not available

Figure 3

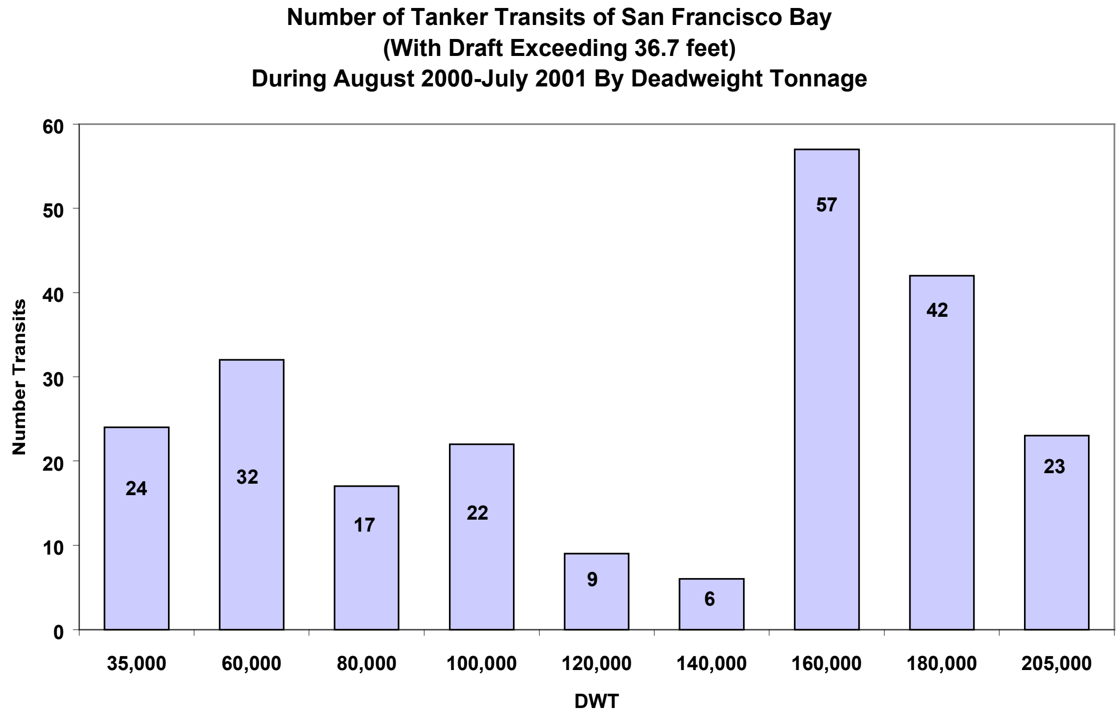


Figure 4

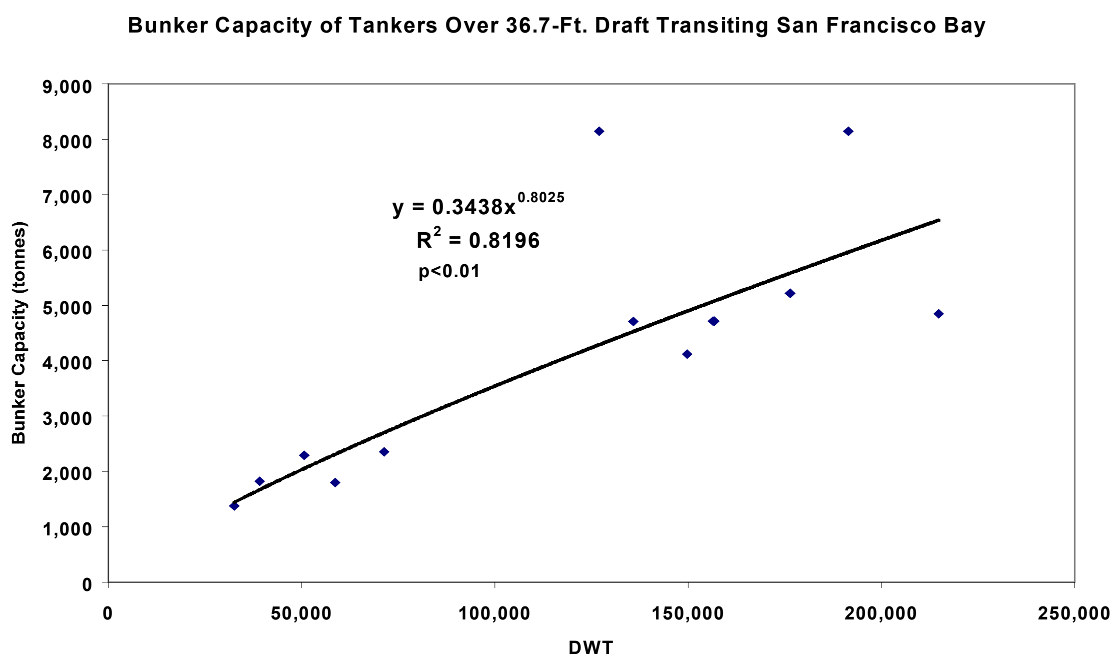


Table 3: Cargo and Bunker Fuel Capacity of Tankers With Over 36.7-Ft. Draft Transiting San Francisco Bay By Deadweight Tonnage Size Class			
Deadweight Tonnage Class	**Annual Number Transits Over 36.7-Ft. Draft[1]**	**Cargo Capacity tonnes (gallons)[2,3] (80% full)**	**Bunker Capacity tonnes (gallons)[2,3] (70% full)**
20,000 – 45,000 DWT	24	36, 700 tonnes (10,790,000 gal)	1,240 tonnes (366,000 gal)
50,000 – 70,000 DWT	32	53,900 tonnes (15,850,000 gal)	1,640 tonnes (481,000 gal)
75,000 – 90,000 DWT	17	68,700 tonnes (20,190,000 gal)	2,040 tonnes (600,000 gal)
95,000 – 110,000 DWT	22	91,400 tonnes (26,880,000 gal)	2,960 tonnes (870,000 gal)
115,000 – 145,000 DWT	15	133,400 tonnes (39,230,000 gal)	4,240 tonnes (1,247,000 gal)
150,000 – 170,000 DWT	57	145,400 tonnes (42,750,000 gal)	3,220 tonnes (947,000 gal)
175,000 – 190,000 DWT	42	155,100 tonnes (45,590,000 gal)	3,750 tonnes (1,103,000 gal)
195,000 – 215,000 DWT	23	184,200 tonnes (54,160,000 gal)	4,500 tonnes (1,322,000 gal)

[1]Based on US Coast Guard Vessel Traffic Service (USCG VTS) data of August 2000 -- July 2001
[2]Gallons derived from tonnage measurements and converted to gallons using 294 gallons/tonne conversion factor.
[3]Based on data in Clarkson Register on individual vessels recorded by USCG VTS

Figure 5

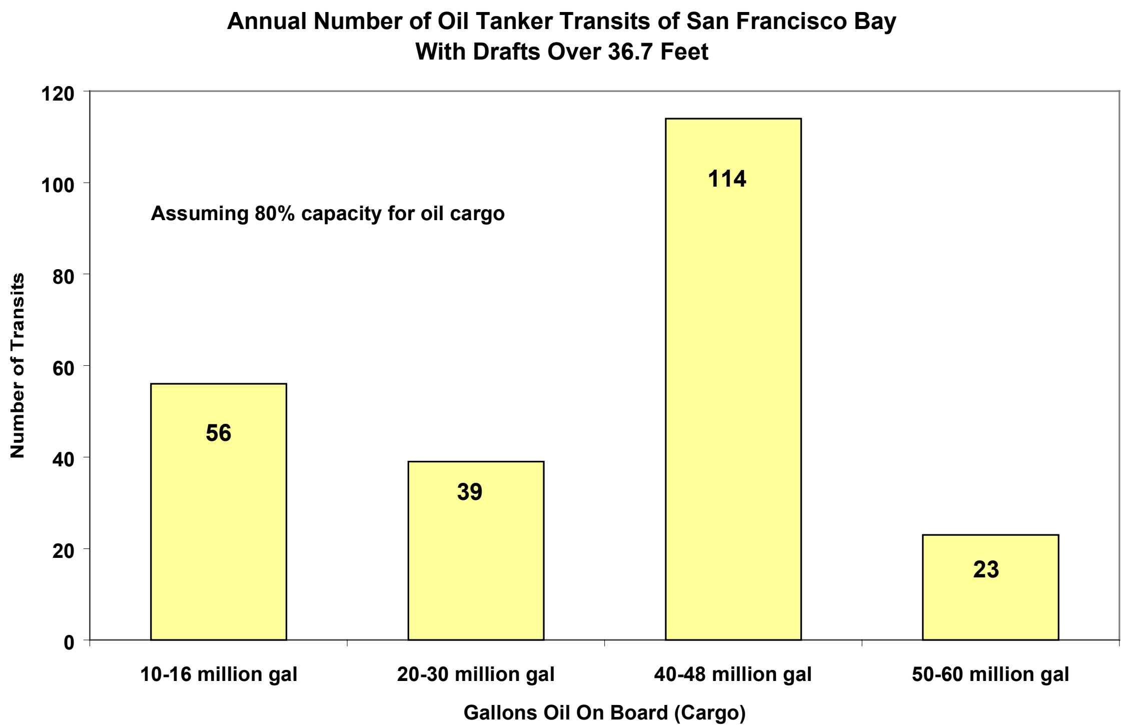
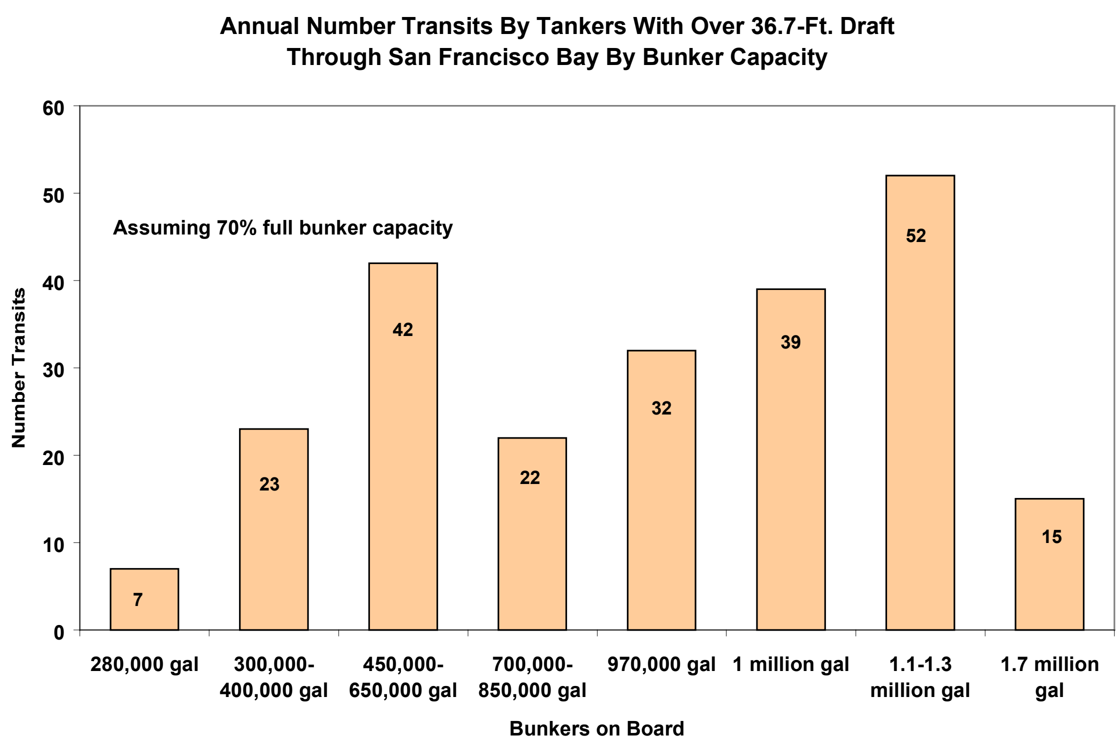


Figure 6



2.1.1 Tanker Spill Scenario Analysis Using US Grounding Data Only

The expected amount of oil cargo spilled – i.e., the percentage of cargo – by tankers in a grounding incident, *provided oil was spilled*, was derived for each DWT class from an analysis of 888 tanker groundings in US waters from 1980-1999. As shown in Table 4, only a small percentage of tanker grounding incidents in US waters resulted in any oil spillage. Since many of these groundings are soft groundings, however, this percentage should not be taken as the probability of spillage as a result of a hard grounding such as might occur on one of the San Francisco Bay rock pinnacles. Table 5 shows the average probability of grounding per tanker transit in US waters. This should be viewed as an overall probability and not necessarily applicable to San Francisco Bay. The specific probability of grounding in San Francisco Bay is dependent on the conditions particular to that location.

Table 6 shows a listing of tanker groundings and the resultant cargo spillage for US waters during 1980-1999.

Table 4: Tanker Groundings in US Waters 1980-1999

Grounding Outcome	Number Incidents	% Total Incidents
No oil spilled	861	96.96%
Spill of 1-9 gallons	4	0.45%
Spill of 10-99 gallons	6	0.68%
Spill of 100-999 gallons	4	0.45%
Spill of 1,000-9,999 gallons	3	0.34%
Spill of 10,000-99,999 gallons	2	0.23%
Spill of 100,000-999,999 gallons	6	0.68%
Spill of 1,000,000-9,999,999 gallons	1	0.11%
Spill of >10,000,000 gallons	1	0.11%
Total grounding incidents	**888**	**100 % (rounding errors)**
Source: Environmental Research Consulting Databases		

Table 5: Estimated Probability of Tanker Grounding Per Trip in US Waters

Average Tanker Groundings Per Year[1]	44.4
Average Tanker Trips Per Year[2]	46,952
Average Groundings/Trip	0.000956
[1]Based on 888 groundings during 1980-1999 [2]Based on average tanker trips reported by Army Corps of Engineers for 1986-1997	

Table 6: Tanker Groundings in US Waters Resulting in Oil Spillage (1980-1999)						
Year	**Tanker name**	**DWT**	**Cargo Capacity (t)**	**Cargo Capacity (gal)**	**Amount Spilled (gals)**	**% Cargo spilled**
1984	Alvenus	57,375	72,000	21,168,000	2,757,258	13.03%
1985	Amersham	88,335	99,000	29,106,000	435,000	1.49%
1986	Viking Osprey	88,726	98,505	28,960,470	264,600	0.91%
1986	Chemical Transport	8,260	8,673	2,549,862	84	0.003%
1987	Glacier Bay	82,000	86,100	25,313,400	207,564	0.82%
1988	Barabara (26 GT)	n/a	n/a	n/a	500	n/a
1988	Frank H. Brown	7,011	7,362	2,164,296	4,494	0.21%
1989	Exxon Valdez	214,860	236,071	69,404,874	336	<0.001%
1989	Exxon Houston	73,000	76,650	22,535,100	8,400	0.04%
1989	Presidente Rivera	88,726	103,000	30,282,000	307,000	1.01%
1989	World Prodigy	29,990	40,000	11,760,000	292,000	2.48%
1989	Exxon Valdez	214,860	236,071	69,404,874	10,500,000	15.13%
1989	Bert Reinauer II	3,981	4,180	1,228,935	50	0.004%
1989	Leona L (569 GT)	n/a	n/a	n/a	5	n/a
1989	Unicorn Derek	1,141	1,200	352,227	10	0.003%
1990	BT Nautilus	64,900	65,126	19,147,044	100	<0.001%
1990	BTNautilus	64,900	65,126	19,147,044	250,000	1.31%
1990	Frank H. Brown	7,011	7,362	2,164,296	36,657	1.69%
1990	Jupiter	10,932	11,479	3,374,708	6	<0.001%
1990	Leona L (569 GT)	n/a	n/a	n/a	10	n/a
1990	Montrachet	30,806	32,346	9,509812	1	<0.001%
1992	June C. (1,149 GT)	n/a	n/a	n/a	100	n/a
1993	Rossi	29,990	40,000	11,760,000	50	<0.001%
1994	Robert Maersk	34,985	38,387	11,285,778	10	<0.001%
1995	Mormacstar	39,862	45,000	13,230,000	15,918	0.12%
1996	Limar	29,999	44,001	12,936,294	1,200	0.01%
1998	Coastal Corpus Christi	52,800	55,440	16,299,360	5	<0.001%
Source: Environmental Research Consulting Databases						

The distribution of percentages of cargo lost (i.e., the cargo outflow divided by the quantity of cargo on board) in a grounding-related spill was derived from this set of incidents (Figure 7). As data on the amount of cargo onboard are unavailable, it was assumed that these tankers were loaded to 80% of their respective capacities.

Although US spills extending over a 15-year period were considered, the dataset of grounding casualties resulting in oil outflow is still relatively small (a total of 13 events). A larger data set would be preferable, but this represents the best available data and is applied in this study.

Recorded spills of less than 1,000 gallons were eliminated from the data set because spills of this smaller size were unlikely to occur with a hard grounding on a rock pinnacle. The expected spill sizes for 14.5-million –gallon and 25-million-gallon product tankers and 44-million- gallon and 55-million-gallon crude tankers, as well as their probabilities of a loss of this size are shown in Table 7.

Figure 7

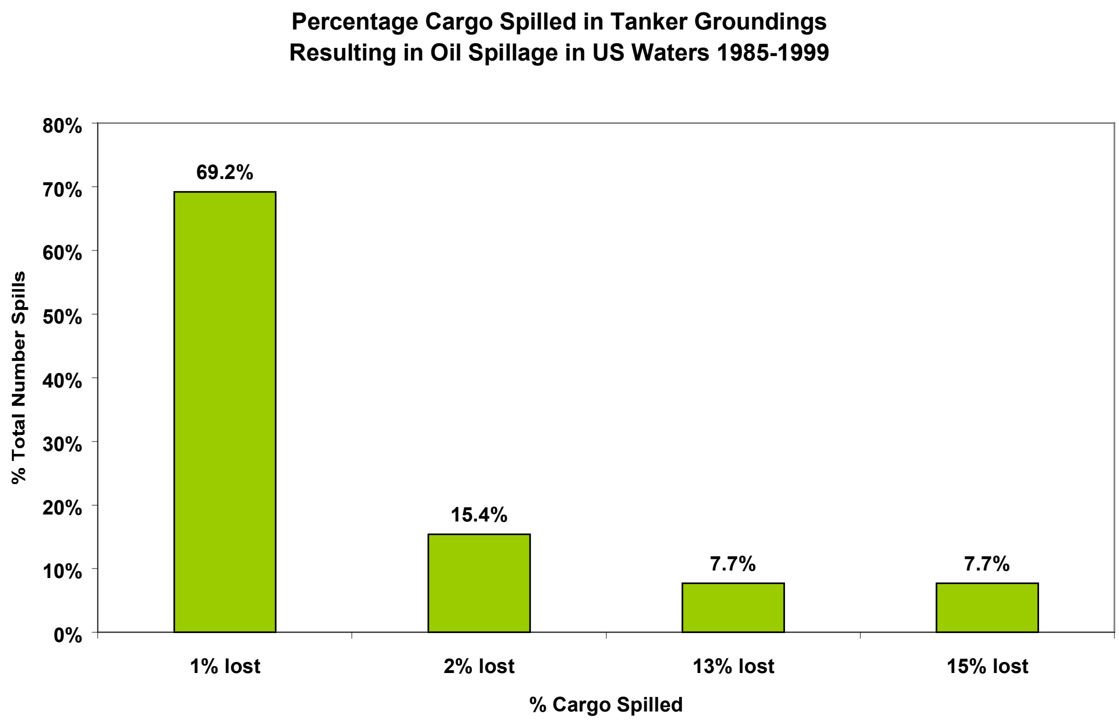


Table 7: Spill Sizes For Tanker Groundings in San Francisco Bay (US Data Only)					
% Cargo Loss[1]	**Tanker Capacity[2]**				**Probability of Loss of This Size if Spill Occurs[1]**
	14,500,000 gal *Product Tanker*	**25,000,000 gal *Product Tanker***	**44,000,000 gal *Crude Tanker***	**55,000,000 gal *Crude Tanker***	
15%	2,175,000	3,750,000	6,600,000	8,250,000	**7.7%**
13%	1,885,000	3,250,000	5,720,000	7,150,000	**7.7%**
2%	290,000	500,000	880,000	1,100,000	**15.4%**
1%	145,000	250,000	440,000	550,000	**69.2%**
Annual Transits[3]	56	39	114	23	**232 total transits**

[1]Based on analysis of 1980-1999 tanker groundings in US waters
[2]Assuming 80% full cargo tanks
[3]Based on San Francisco USCG VTS Operations data August 2000-July 2001

From the data in Table 7, the expected cumulative probability distribution of spills from product and crude tankers were derived based on the actual probabilities of loss of various percentages of cargo from the available tanker grounding spill data (Figure 7) were applied to give the results shown in Figure 8. Table 8 gives the derived 20th, 50th, and 95th percentile spill sizes.

Figure 8

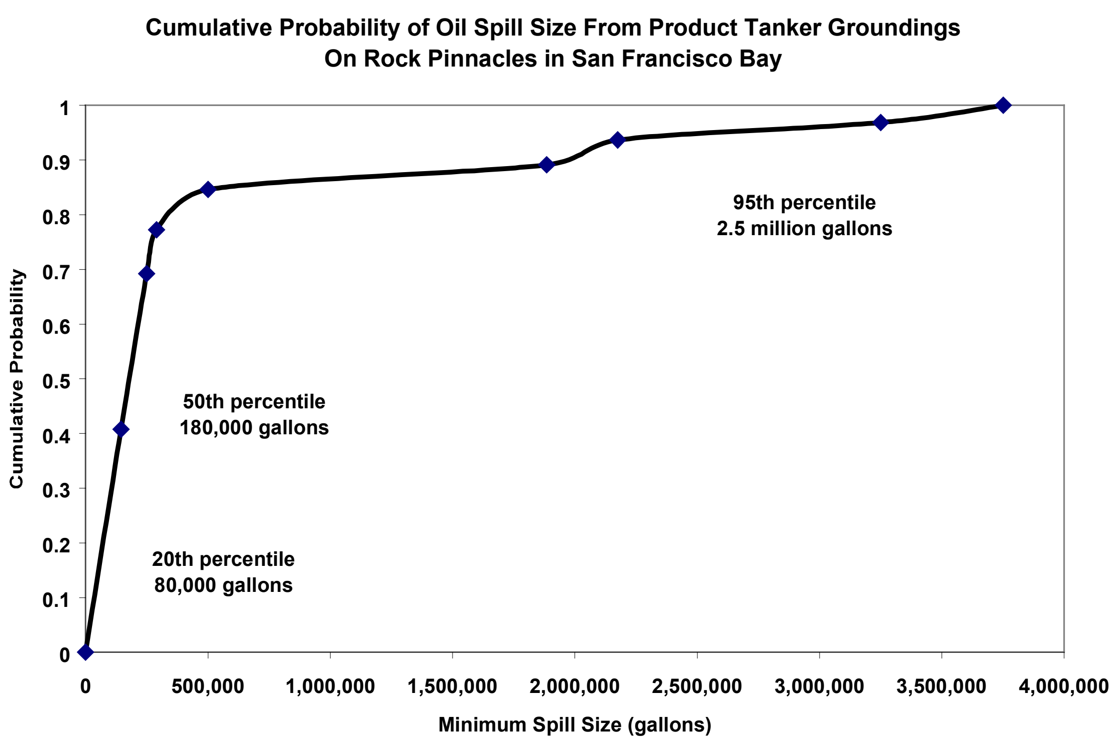
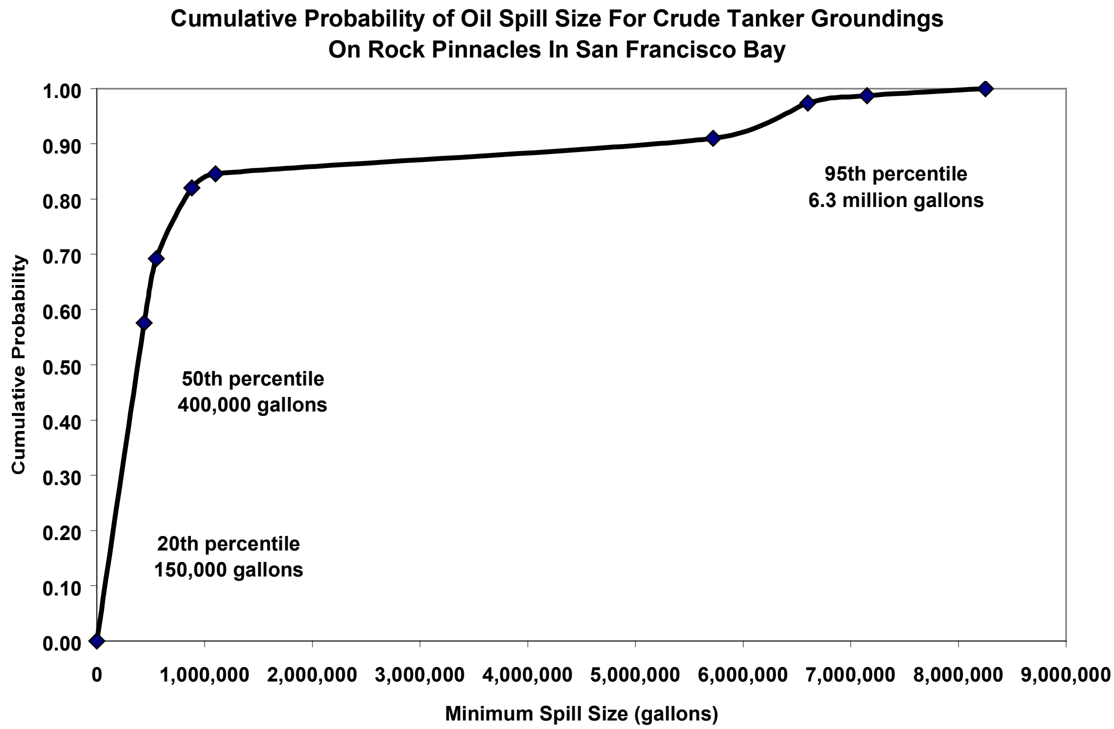


Figure 9



The derived spill scenarios for tanker groundings in San Francisco Bay are shown in Table 8.

Table 8: Oil Spill Scenarios For Tanker Groundings on Rock Pinnacles In San Francisco Bay Based on US Data Only			
Tanker Type	**20th Percentile**	**50th Percentile**	**95th Percentile**
Product Tanker	80,000 gallons	180,000 gallons	2.5 million gallons
Crude Tanker	150,000 gallons	400,000 gallons	6.3 million gallons

2.1.2 Tanker Spill Scenario Analysis Using International Grounding Data

The relatively small data set on tanker groundings in US waters called into question the use of international tanker grounding data. The spill scenario analysis was therefore repeated using international data (including US data). International oil spill data are less comprehensive than US data because of a lack of accurate reporting and inconsistencies in data collection processes in other nations. This is particularly true of smaller spills. The oil spill data set in the Environmental Research Consulting Databases is incomplete for spills of less than 10,000 gallons. The use of this incomplete data for smaller spills might therefore slightly increase the lower spill volumes (20th and 50th percentile) than might be expected if a complete data set were available. In this analysis, both US and international spills under 1,000 gallons were eliminated as these were deemed to represent soft groundings. Oil spills from tankers due to groundings from the international data set are shown in Table 9. The results of the analyses are shown in Figures 10-12 and Table 10.

Table 9: International Tanker Groundings Resulting in Oil Spillage of At Least 1,000 Gallons[1]						
Year	**Tanker Name**	**DWT**	**80% Cargo Capacity (t)**	**80% Cargo Capacity (gal)**	**Amount Spilled (gal)**	**% Cargo Spilled**
1984	Alvenus	57,375	72,000	21,168,000	2,757,258	13.03%
1985	Saint Helen	48,000	42,113	11,454,864	29,000	0.25%
1985	Bridgeness	1,000	857	233,143	46,000	19.73%
1985	Sansho Maru	2,000	1,714	466,286	154,000	33.03%
1985	Ekfjord	2,000	1,714	466,286	154,000	33.03%
1985	Amersham	88,335	99,000	29,106,000	435,000	1.49%
1986	Thuntank 5	5,000	4,286	1,165,714	58,800	5.04%
1986	OBO Valparaiso	128,000	109,714	29,842,286	630,000	2.11%
1986	Viking Osprey	88,726	98,505	28,960,470	264,600	0.91%
1987	Lunamar II	58,000	49,714	13,522,286	1,000	0.01%
1987	Mercator	29,687	30,204	8,215,510	29,400	0.36%
1987	Stolt Avance	23,276	23,803	6,474,488	59,000	0.91%
1987	Antonio Gramsci	39,870	37,844	10,293,590	294,000	2.86%
1987	El Hani	155,000	132,857	36,137,143	882,000	2.44%
1987	Petrolero Cabo Pilar-Chileno	69,000	59,143	16,086,857	2,058,000	12.79%
1987	Glacier Bay	82,000	86,100	25,313,400	207,564	0.82%
1988	Avar	152,395	132,096	35,930,201	29,000	0.08%
1988	Golar Liz	272,000	233,143	63,414,857	147,000	0.23%
1988	Oshima Spirit	90,000	77,143	20,982,857	1,470,000	7.01%
1989	Theoskepasti	950	814	221,486	35,000	15.80%
1989	Lauberhorn	138,538	118,747	32,299,145	441,000	1.37%
1989	Kanchenjunga	284,000	243,429	66,212,571	852,600	1.29%
1989	Presidente Rivera	88,726	103,000	30,282,000	307,000	1.01%
1989	World Prodigy	29,990	40,000	11,760,000	292,000	2.48%
1989	Exxon Valdez	214,860	236,071	69,404,874	10,500,000	15.13%
1990	BT Nautilus	64,900	65,126	19,147,044	250,000	1.31%
1990	Frank H. Brown	7,011	7,362	2,164,296	36,657	1.69%
1990	Capahuari	25,648	28,800	8,467,200	460,000	5.43%
1991	Eastern Shell	5,947	6,303	1,853,141	40,000	2.16%
1991	Nejmat El Petrol XVIII	6,210	6,260	1,840,440	35,000	1.90%
1991	Sea Tiger	22,639	22,639	6,655,866	29,000	0.44%
1992	Aida	40,000	40,000	11,760,000	15,000	0.13%
1992	Aegean Sea	114,036	114,036	33,526,584	21,900,000	65.32%
1992	Maasdijk	33,451	37,483	10,195,448	3,000	0.03%
1993	Betula	10,033	10,033	2,949,702	11,000	0.37%

Table 9: International Tanker Groundings Resulting in Oil Spillage of At Least 1,000 Gallons[1] (continued)						
Year	**Tanker Name**	**DWT**	**80% Cargo Capacity (t)**	**80% Cargo Capacity (gal)**	**Amount Spilled (gal)**	**% Cargo Spilled**
1993	Frontier Express	68,520	65,487	19,253,237	2,470,000	12.83%
1993	Iliad	83,466	82,400	24,225,600	235,200	0.97%
1993	Braer	89,730	89,730	26,380,620	25,000,000	94.77%
1993	Sam Bu No. 11	1,600	1,827	496,927	1,300	0.26%
1994	Auce	5,045	5,045	1,483,230	13,200	0.89%
1994	Pamela	25,000	25,000	7,350,000	323,000	4.39%
1994	Guilia Seconda	33,402	34,868	9,484,029	3,000	0.03%
1995	Mormacstar	39,862	45,000	13,230,000	15,918	0.12%
1995	Kreva	4,471	4,471	1,314,474	26,400	2.01%
1995	Abbeydale	60,953	52,589	15,461,107	187,000	1.21%
1995	General Aslanov	12,334	42,113	11,454,864	1,000	0.01%
1995	Sibyl W.	752	645	175,323	2,940	1.68%
1996	An Fu	61,335	55,200	16,228,800	29,000	0.18%
1996	Sea Empress	147,273	128,698	37,837,330	21,274,000	56.22%
1997	Konemu	1,082	1,082	318,108	59,000	18.55%
1997	Serifos	46,700	40,626	11,944,162	265,000	2.22%
1997	San Jorge	67,031	57,178	16,810,450	1,320,000	7.85%
1997	Nissos Amorgos	89,426	78,930	23,205,538	2,520,000	10.86%
1997	Diamond Grace	259,999	249,427	73,331,597	441,000	0.60%
1998	Ocean Gurnard	13,611	12,677	3,726,979	117,600	3.16%
1998	Santa Anna	28,000	28,000	8,232,000	82,320	1.00%
1999	Nefterudovoz 7	2,871	2,871	844,074	88,200	10.45%
2000	Kingfisher	60,585	59,200	17,404,800	294,000	1.69%
2000	Natuna Sea	89,922	79,619	23,408,045	2,058,823	8.80%

Source: Environmental Research Consulting Oil Spill Databases
[1]Shaded spills represent catastrophic drift groundings.

Three drift groundings – the T/V Sea Empress, the T/V Braer, and the T/V Aegean Sea – in which 56-95% of the total cargo onboard was lost due to extreme damage to the vessel were also eliminated from the analysis. The size of the 95th percentile spill would be significantly biased by the extremely large cargo losses in these three incidents. This type of drift grounding with complete loss of control of the tanker in a storm is extremely unlikely in San Francisco Bay based on studies conducted for the US Coast Guard by Herbert Engineering, *et al*. (1999).

If a tanker remains afloat, the oil outflow from a grounding incident is generally limited to about 15% to 20% of the cargo payload. This is because once the oil inside the cargo tanks reaches hydrostatic balance with the seawater below, the outflow of oil stops. A drift grounding occurs when a vessel loses its ability to navigate (e.g. though loss of propulsion, steering, or towline separation), and is blown aground before it can get underway or is taken under tow. In such cases, the vessel repeatedly impacts the ground and frequently breaks up.

Drift groundings are relatively low probability events, comprising approximately 10% of all grounding events that lead to oil spills. Studies have also shown that the risk of drift grounding is significantly reduced when tugs of sufficient size are in the vicinity of a stricken vessel, and sea states are not extreme (Herbert Engineering *et al*., 1999). Within San Francisco Bay, where escort tugs are required for laden tankers and wave conditions are relatively benign as compared to offshore locations, the likelihood of a drift grounding resulting in breakup of the vessel is considered extremely low. Therefore, the coastwise drift grounding events contained in the international data set were excluded when estimating the spill sizes for tankers.

Table 11: Spill Sizes For Tanker Groundings in San Francisco Bay (Using International Data)

% Cargo Loss[1]	Tanker Capacity[2]				Probability of Loss of This Size if Spill Occurs[1]
	14,500,000 gal *Product Tanker*	**25,000,000 gal *Product Tanker***	**44,000,000 gal *Crude Tanker***	**55,000,000 gal *Crude Tanker***	
20% loss	2,900,000	5,000,000	8,800,000	11,000,000	**3.6%**
14% loss	2,030,000	3,500,000	6,160,000	7,700,000	**3.6%**
10% loss	1,450,000	2,500,000	4,400,000	5,500,000	**8.9%**
8% loss	1,160,000	2,000,000	3,520,000	4,400,000	**5.4%**
5% loss	725,000	1,250,000	2,200,000	2,750,000	**8.9%**
2% loss	290,000	500,000	880,000	1,100,000	**21.4%**
1% loss	145,000	250,000	440,000	550,000	**23.2%**
0.2% loss	29,000	50,000	88,000	110,000	**25.0%**
Annual Transits[3]	**56**	**39**	**114**	**23**	**232 total transits**

Analysis by Environmental Research Consulting
[1]Based on analysis of 1980-1999 tanker groundings in US waters and 1990-199 groundings in international waters
[2]Assuming 80% full cargo tanks
[3]Based on San Francisco USCG VTS Operations data August 2000-July 2001

Figure 10

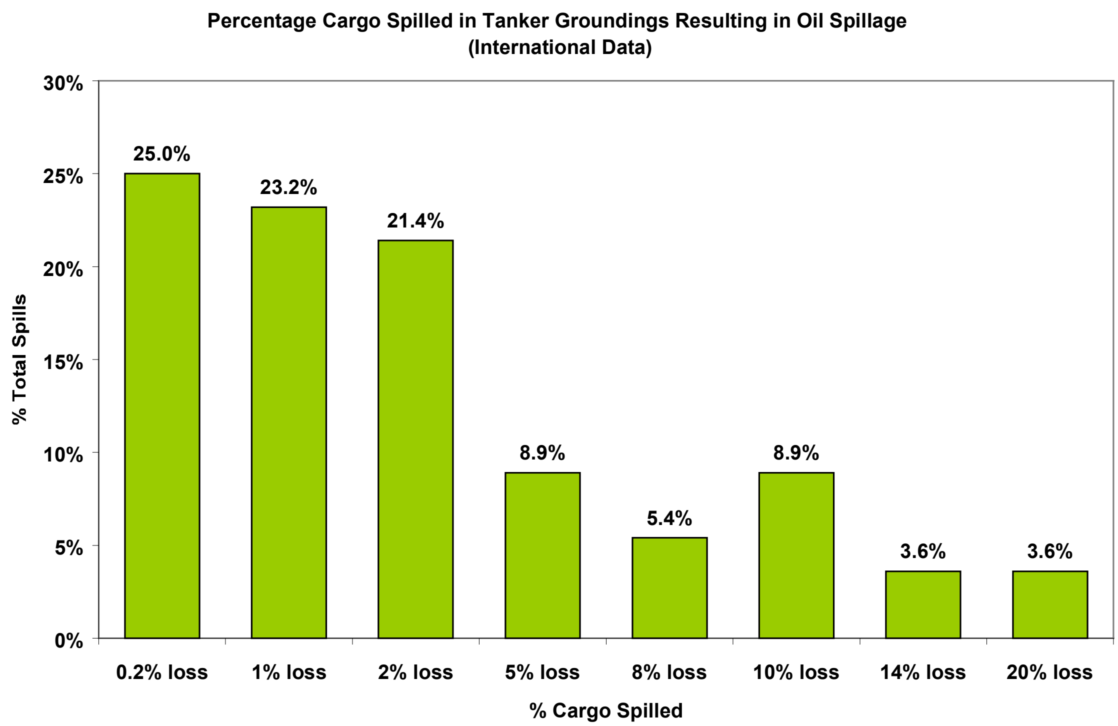


Figure 11

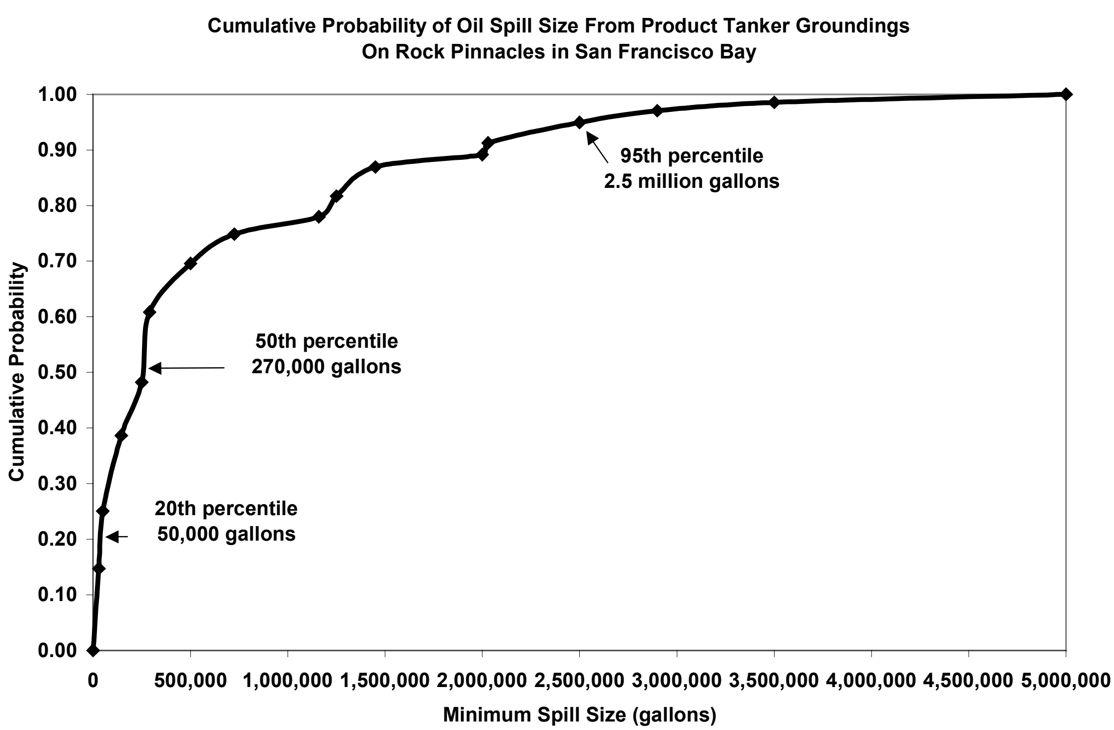
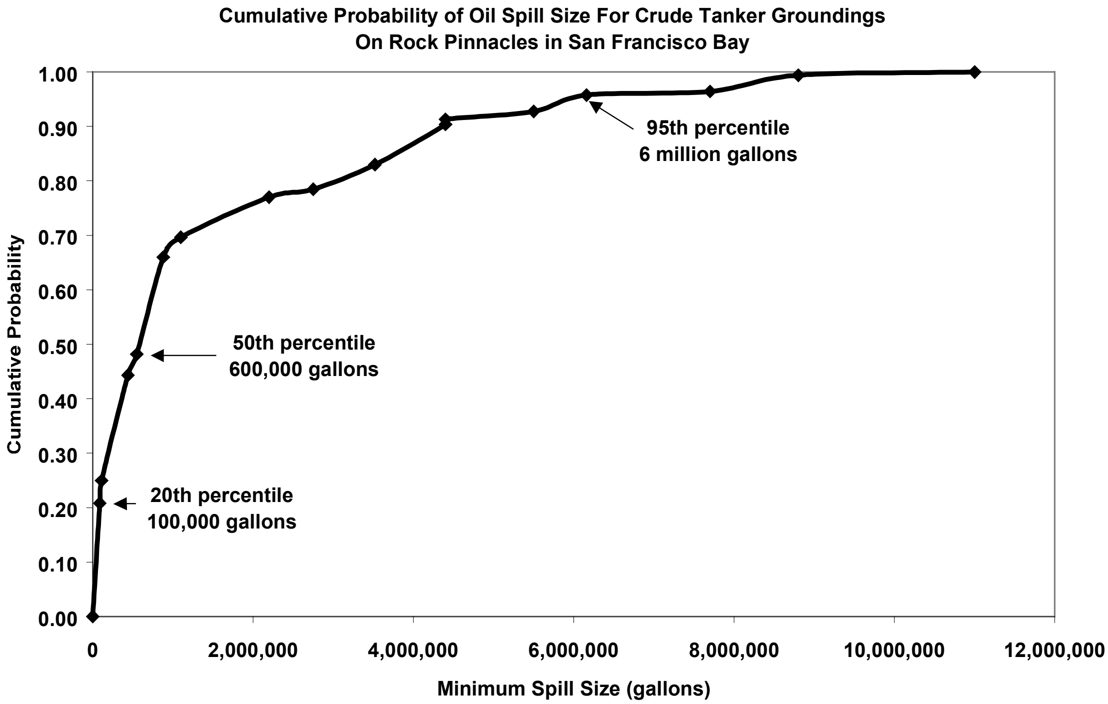


Figure12



The results of the both the US and international analyses are shown in Table 12.

Table 12: Oil Spill Scenarios For Tanker Groundings on Rock Pinnacles In San Francisco Bay Based on International Data

Tanker Type	20^{th} Percentile	50^{th} Percentile	95^{th} Percentile
Product Tanker ***(US data only)***	80,000 gallons	180,000 gallons	2,500,000 gallons
Product Tanker ***(International data)***	50,000 gallons	270,000 gallons	2,500,000 gallons
Crude Tanker ***(US data only)***	150,000 gallons	400,000 gallons	6,300,000 gallons
Crude Tanker ***(International data)***	100,000 gallons	600,000 gallons	6,000,000 gallons

2.1.3 Influence of Implementation of Double-Hulls in Tanker Construction

These spill scenarios should be viewed as conservative (i.e., as somewhat *larger* than might be actually be expected with improvements in spill prevention). The historical spill data is largely based on single hull tanker casualties. The continued changeover from single-skinned to double hull vessels over the next several years will reduce the likelihood of a grounding causing any spillage as well as reduce the size of a spill from a grounding incident (see Figure 13).

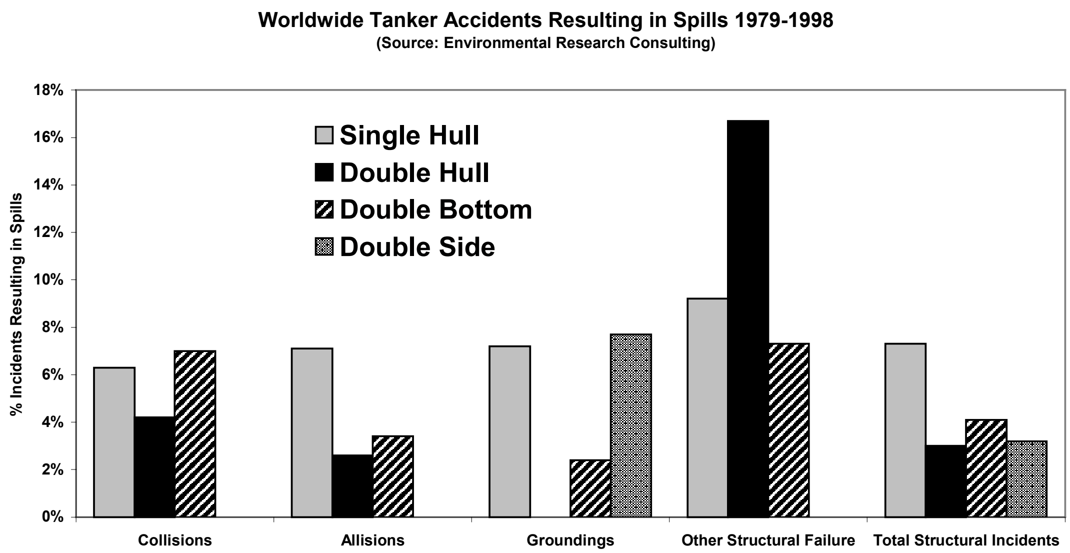


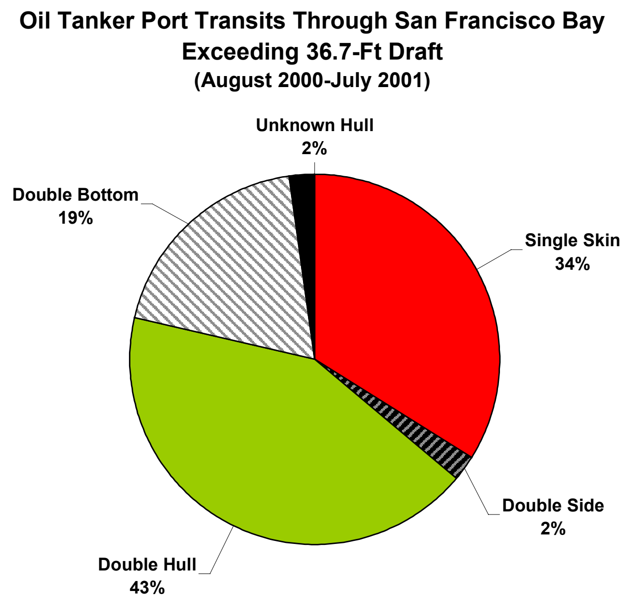
Figure 13

The tanker transits through San Francisco Bay during the previous 12 months involved 62% of tankers that were either double hull or double-bottomed (Figure 14).

The Oil Pollution Act of 1990 (OPA 90) and MARPOL 73/78 mandate retirement of single hulls for tankers by the year 2010. All tankers must have double hulls by this date. The continued introduction of double hull tankers and elimination of single hulls will influence the expected spill volumes for the tanker spill scenarios. Various studies, including that shown in Figure 13, have indicated that double hull tankers are less likely to spill oil in the event of grounding. The probability of oil outflow due to grounding damage is, however, beyond the purview of this analysis.

Studies on the size of spills expected from grounding incidents involving double hull tankers have demonstrated that the size of the largest outflows are expected to be reduced from that of spills of single hull tankers. The sizes of the median and smaller spills from double hull tankers are expected to remain similar to those of single hull tankers.

Figure 14



Although over one-third of the world's tanker fleet is now double hull, many of the double hull tankers have been constructed in the last few years. The sparseness of grounding spills from double hull tankers gives reason to believe that this design is effective in mitigating spillage, but there are still insufficient spill statistics to reliably estimate their expected spill volume. Therefore, probabilistic outflow calculations have been carried out to assess the relative effectiveness of double hulls.

The IMO guidelines for evaluating alternative tanker designs (IMO 1995) contain a probabilistic-based procedure for assessing oil outflow performance. Probability density functions describing the location, extent and penetration of side and bottom damage are applied to a vessel's compartmentation, generating the probability of occurrence and collection of damaged compartments associated with each possible damage incident. Table 13 contains a summary of outflow calculations for a series of actual tankers, representative of the sizes of tankers transiting San Francisco Bay.

Three sizes of tankers were evaluated: Panamax (about 40,000 DWT), Aframax (about 90,000 DWT), and 125,000 DWT crude oil carriers. A pre-MARPOL and a MARPOL 73/78 configuration were evaluated for each size of single hull tanker. The Panamax double hull tankers have two-meter-wide wing tanks and double bottoms, and centerline bulkheads. The Aframax double hull tankers have double hull dimensions between 2.3 and 2.5 meters. Aframax design #1 has a single-tank-across cargo tank arrangement, whereas design #2 has a centerline bulkheads. The 125,000 DWT double hull tankers are representative of the tankers being specially designed and built for the Alaskan North trade. These tankers, arranged with wide double hull dimensions (typically 2.8 to 2.0

meters) and longitudinal sub-division throughout the cargo block, have very good outflow characteristics.

SINGLE HULL TANKERS		Panamax #1	Panamax #2	Aframax #1	Aframax #2	125K dwt #1	125K dwt #2	Average
Side	Prob. Of Zero Outflow (Po)	0.31	0.54	0.22	0.32	0.24	0.34	0.33
	Average Spill Size	8%	4%	12%	11%	8%	8%	8%
	Extreme Spill Size	15%	12%	20%	16%	15%	11%	15%
Bottom	Prob. Of Zero Outflow (Po)	0.13	0.10	0.09	0.09	0.08	0.08	0.09
	Average Spill Size	5%	8%	5%	9%	5%	8%	7%
	Extreme Spill Size	15%	23%	13%	21%	11%	17%	17%
Combined	Prob. Of Zero Outflow (Po)	0.20	0.28	0.14	0.19	0.14	0.18	0.19
	Prob. of Outflow (1-Po)	0.80	0.72	0.86	0.81	0.86	0.82	0.81
	Mean Outflow Parameter	0.047	0.053	0.062	0.081	0.049	0.062	0.059
	Average Spill Size	6%	7%	7%	10%	6%	8%	7%
	Extreme Spill Size	15%	19%	16%	19%	13%	15%	16%

DOUBLE HULL TANKERS		Panamax #1	Panamax #2	Aframax #1	Aframax #2	125K dwt #1	125K dwt #2	Average
Side	Prob. Of Zero Outflow	0.85	0.85	0.85	0.87	0.82	0.90	0.85
	Average Spill Size	11%	11%	20%	16%	11%	11%	13%
	Extreme Spill Size	13%	13%	25%	19%	14%	11%	16%
Bottom	Prob. Of Zero Outflow	0.84	0.84	0.81	0.80	0.82	0.82	0.82
	Average Spill Size	7%	7%	9%	7%	6%	5%	7%
	Extreme Spill Size	10%	10%	13%	11%	8%	8%	10%
Combined	Prob. Of Zero Outflow	0.84	0.84	0.82	0.83	0.82	0.85	0.83
	Prob. of Outflow (1-Po)	0.16	0.16	0.18	0.17	0.18	0.15	0.17
	Mean Outflow Parameter	0.013	0.013	0.022	0.017	0.014	0.010	0.015
	Average Spill Size	8%	8%	13%	10%	8%	7%	9%
	Extreme Spill Size	11%	11%	18%	14%	11%	9%	12%

Table 13 Probabilistic Outflow Analysis of Tankers

The IMO methodology calls for calculation of three outflow parameters:

- The *probability of zero outflow*, P_0, represents the likelihood that *no oil* will be released into the environment, given a collision or grounding casualty which breaches the outer hull. P_0 equals the cumulative probability of all damage cases with no outflow.
- The *mean outflow parameter*, O_M, is the non-dimensionalized mean or expected outflow, and provides an indication of a design's overall effectiveness in limiting oil outflow. The mean outflow equals the sum of the products of each damage case probability and the associated outflow. O_M equals the mean outflow divided by the total quantity of oil onboard the vessel.
- The *extreme outflow parameter*, O_E, is the non-dimensionalized extreme outflow, and provides an indication of the expected oil outflow from particularly severe casualties. The extreme outflow is the weighted average of the upper 10% of all casualties (i.e. all damage cases within the cumulative probability range from 0.9 to 1.0).

Comparing the mean outflow parameters, we find that the expected outflows from double hull tankers involved in groundings are 1/4 to 1/5 of the amounts expected from single hull vessels. Dividing the mean outflow parameter by the probability of outflow (1-Po) gives the average spill size as a percent of the payload. Based on the probabilistic analysis, the average spill size for single hull and double hull vessels involved in groundings are roughly equal. The average spill sizes for the extreme (1/10 largest) spills of tankers involved in groundings are 17% of payload for single hull tankers and 10% of payload for double hull tankers. Thus, it is projected that the very large spills for double hull tankers will be approximately 59% of the size of the very large spills from single hull tankers.

It should be noted that the IMO probabilistic approach does not account for differences in crashworthiness between designs. Recent research (Rawson, 1998) suggests that the double hull structure is effective in mitigating the extent of damage and the expected outflow from collisions and groundings. In particular, the longitudinal extent of damage is reduced for high-energy impacts. Also, further reductions in spill size are anticipated due to the OPA 90 requirements for vessel response plans and spill response training

For the purposes of this study, the average spill sizes from single hull and double hull configurations is conservatively assumed equal, which is consistent with the results of the probabilistic analysis (refer to Table 1). Therefore, we have directly applied the 20th percentile and 50th percentile spill sizes developed from the historical spill data.

In the case of the 95th percentile spill, a 50% reduction in spill size is assumed once the world's tanker fleet is fully double hull. This is based on the calculated 59% reduction, and the expected benefits of improved crash-worthiness of double hull tankers. Incorporating the expected reduction of spill size from double hull tankers into the spill scenario analysis for San Francisco Bay would change the sizes of the 95th percentile spills as shown in Table 14. Spills from double hull tankers would be expected to be 50% of that of single hull tankers for the largest spills. The median and smaller spills would not change.

Table 14: Influence of Double Hulls on Oil Spill Scenarios For Tanker Groundings on Rock Pinnacles In San Francisco Bay

Tanker Type	**Expected Spill Volumes**		
	20th Percentile	**50th Percentile**	**95th Percentile**
Single hull Product Tanker	50,000 gallons	270,000 gallons	2,500,000 gallons
Double hull Product Tanker	50,000 gallons	270,000 gallons	1,250,000 gallons
Single hull Crude Tanker	100,000 gallons	600,000 gallons	6,000,000 gallons
Double hull Crude Tanker	100,000 gallons	600,000 gallons	3,000,000 gallons

2.2 Bunker Spillage From Tanker Groundings

The double hull tankers built since 1990 typically carry their bunkers in upper wing tanks. The probability that these tankers will be breached in a rock pinnacle grounding scenarios is very low. Some spillage will occur if a tanker sinks, but floundering and capsizing events are highly unlikely due to the subdivision and damage stability characteristics of modern tankers. For this reason, modeling for bunker spills from tankers was not conducted for this study.

2.3 Selection of Oil Types for Tanker Scenarios

In order to determine the appropriate oil types for the spill scenarios, the petroleum products and crude oil types that are transported in tankers through San Francisco Bay were determined from Army Corps of Engineers Waterborne Commerce data (1997 data). During 1997, 5,493,000 short tons of gasoline and 3,095,000 short tons of diesel fuel were transported through San Francisco Bay. Gasoline and diesel fuel were selected as the two products likely to be spilled from product tankers. It was determined that both of these products should be included in the modeling work since the two products behave differently and have different environmental and economic impacts when spilled.

The next largest category of petroleum product transport was residual fuel oil of which just over 1 million short tons were transported. If necessary, the impacts of a residual fuel oil spill might be derived from the modeling that will be conducted on the heavy fuel oil in bunker fuel spills from freighters. The most common crude oil transported through San Francisco Bay is North Slope crude.

2.4 Cargo Vessels Bunker Spill Analysis

The methodology for deriving the 20th percentile, 50th percentile, and 95th percentile tanker cargo spills was used to determine the same set of scenarios for cargo vessel bunker fuel spills using both US and international data sets. The 569 transits of cargo vessels (including container vessels, bulk carriers, freighters, and other freight-carrying vessels) exceeding 36.7-feet in draft are shown by DWT class in Figure 15. Vessels with at least four transits in the last year are shown in Table 15.

Figure 15

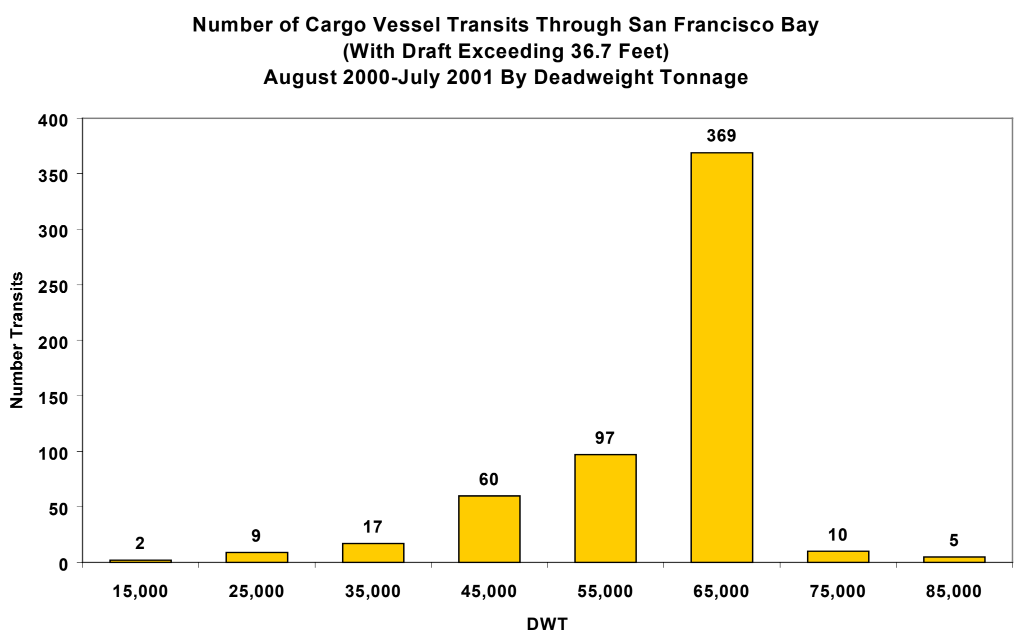


Table 15: Cargo Vessels With At Least Four Transits of San Francisco Bay With Draft of Over 36.7 feet During August 2000-July 2001						
# Transits >36.7-ft. draft[1]	Vessel Name[1]	Vessel Type	DWT[2]	Avg. Draft[1]	Bunker Capacity[2] (tonnes)	Fuel[2]
19	Maren Maersk	Container	60,640	36.9	n/a	HFO
19	Marit Maersk	Container	60,890	41.9	n/a	HFO
18	Mathilde Maersk	Container	62,900	36.7	n/a	n/a
17	Magleby Maersk	Freight	60,350	43.4	n/a	n/a
17	Mckinney Maersk	Container	60,350	36.9	n/a	n/a
16	Marie Maersk	Container	66,480	37.2	n/a	n/a
16	Mayview Maersk	Container	60,350	42.9	n/a	n/a
15	Mette Maersk	Container	60,900	43.6	n/a	n/a
14	Marchen Maersk	Container	60,640	41.7	n/a	HFO
13	Apl Spinel	Container	66,512	36.7	7,000	HFO
13	Apl Tourmaline	Container	59,780	40.0	6,450	HFO
13	Apl Turquoise	Container	62,318	37.2	6,450	HFO
13	Madison Maersk	Container	60,350	38.7	n/a	n/a
12	Glasgow Maersk	Container	62,242	40.6	n/a	n/a
11	Apl Sardonyx	Container	66,647	40.2	7,000	HFO
11	Margrethe Maersk	Container	60,639	43.3	n/a	HFO
9	Apl Jade	Container	68,892	40.2	7,000	HFO
8	Essen Express	Container	67,649	39.0	7,353	HFO
8	Hamburg Express	Container	88,447	37.2	7,353	HFO
8	Hanjin Copenhagen	Container	71,375	37.3	n/a	HFO
7	Apl Garnet	Container	66,618	36.7	7,000	HFO
7	Peninsular Bay	Container	59,284	38.6	5,294	HFO
7	Singapore Express	Container	54,766	40.1	n/a	n/a
6	Concord Bridge	Container	51,805	37.2	n/a	n/a
6	Hanjin Athens	Container	69,447	37.0	n/a	HFO
6	Hoechst Express	Container	67,680	37.0	7,353	HFO
6	Jervis Bay	Container	59,093	36.8	5,924	HFO
6	Providence Bay	Container	59,093	37.6	5,924	HFO
6	Star Dieppe	Freight	42,402	38.5	n/a	n/a
5	Colombo Bay	Container	59,093	38.6	6,496	HFO
5	Hanjin Berlin	Container	67,236	36.7	n/a	n/a
5	Hanjin Brussels	Container	68,790	37.7	n/a	HFO
5	Hanjin Washington	Container	67,272	39.0	n/a	n/a
5	Hong Kong Express	Container	45,363	37.2	n/a	n/a

Table 15: Cargo Vessels With At Least Four Transits of San Francisco Bay With Draft of Over 36.7 feet During August 2000-July 2001 (continued)						
# Transits >36.7-ft. draft[1]	**Vessel Name[1]**	**Vessel Type**	**DWT[2]**	**Avg. Draft[1]**	**Bunker Capacity[2] (tonnes)**	**Fuel[2]**
5	Ludwigshafen Express	Container	67,680	39.6	7,353	HFO
5	Rj Pfeiffer	Container	28,555	36.7	2,309	HFO
5	Victoria Bridge	Container	51,805	36.9	n/a	n/a
4	California Jupiter	Container	38,438	39.6	n/a	n/a
4	Cape May	Container	38,217	36.8	4,408	HFO
4	Dirch Maersk	Container	62,418	37.8	n/a	IFO
4	Hanjin Amsterdam	Container	69,447	40.2	n/a	HFO
4	Hanjin Geneva	Container	67,900	38.0	n/a	n/a
4	Hanjin London	Container	67,298	37.1	n/a	n/a
4	Hanjin Paris	Container	67,298	36.7	n/a	n/a
4	Hannover Express	Container	67,680	40.6	7,353	HFO
4	Oocl Hong Kong	Container	67,637	37.0	6,838	HFO
4	Oriental Bay	Container	59,283	37.0	5,294	HFO
4	President Jackson	Freight	53,805	37.6	n/a	n/a
4	Repulse Bay	Container	59,093	39.2	5,924	HFO
4	Shenzhen Bay	Container	59,147	40.2	5,924	HFO
4	Singapore Bay	Freight	59,283	37.2	5,924	HFO
4	Star Davanger	Freight	43,793	37.0	n/a	n/a
4	Star Grip	Freight	43,712	38.0	n/a	n/a
[1]US Coast Guard Vessel Traffic Service Operations, San Francisco, California [2]Clarkson Register, London, UK (n/a = not available)						

The bunker fuel capacity of the cargo vessels was determined from vessel records in the Clarkson Register or, if not available in this source, derived from the regression equation shown in Figure 16. The bunker capacities by DWT class are shown in Table 16.

Figure 16

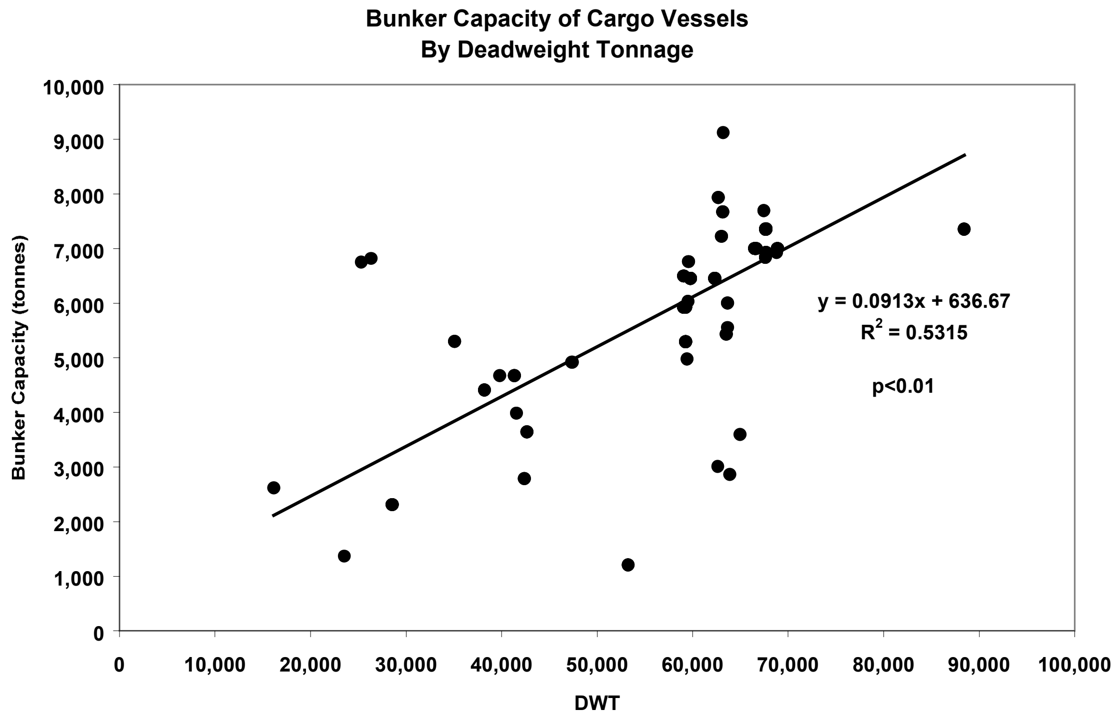


Table 16: Bunker Fuel Capacity of Freight Vessels With Over 36.7-Ft. Draft Transiting San Francisco Bay		
Deadweight Tonnage Class	**Annual Number Transits Over 36.7-Ft. Draft[1]**	**Bunker Capacity tonnes (gallons)[2,3] (70% full)**
10,000 - 19,000 DWT	2	1,730 t (507,000 gal)
20,000 - 29,000 DWT	9	2490 t (731,000 gal)
30,000 - 39,000 DWT	17	3,080 t (906,000 gal)
40,000 - 49,000 DWT	60	3,180 t (934,000 gal)
50,000 - 59,000 DWT	97	4,020 t (1,182,000 gal)
60,000 - 69,000 DWT	369	4,570 t (1,345,000 gal)
70,000 - 70,000 DWT	10	5,050 t (1,484,000 gal)
80,000 - 89,000 DWT	5	5,150 t (1,513,000 gal)

[1]Based on US Coast Guard Vessel Traffic Service data of August 2000 -- July 2001
[2]Gallons derived from tonnage measurements and converted to gallons using a 278 gallons/tonne conversion factor. (Note tonnes = metric tons)
[3]Based on Clarkson Register on individual vessels recorded by USCG VTS and estimation of bunker capacity from formula in Figure 14.

2.4.1 Freighter Spill Scenario Analysis Using US Data Only

The cargo vessel groundings and the relative percentages of bunker fuel spilled in US waters during 1985-2000 are shown in Tables 17-18.

Table 17: Oil Spills Due to Groundings of >300 GRT Non-Tank Vessels In US Waters (1985-2000)

Year	Vessel Name	Vessel Type	GRT	DWT	Gallons Spilled
1985	American Legion	Freight Ship	18,775	22,138	80,000
1991	Vitoria	Freight Ship	14,728	26,479	1
1993	Theodore C	Freight Ship	29,897	52,608	20
1994	Nieuw Amsterdam	Passenger	33,930	3,850	260
1994	Starward	Passenger	12,948	3,241	100
1995	Northern Wind	Freight Ship	494	1,745	20,000
1995	Star Princess	Passenger	63,524	n/a	50
1995	Star Princess	Passenger	63,524	n/a	25
1996	Cape Chalmers	Freight Ship	9,296	12,684	1
1997	Kuroshima	Fish Freighter	4,160	4,845	47,000
1997	Bobo	Freight Ship	32,903	26,523	40,000
1999	Redfin	Freight Ship	482	n/a	200
1999	New Carissa	Wood chip carrier	36,571	44,527	70,000
Source: Environmental Research Consulting Databases					

Table 18: % Bunker Fuel Spilled in Oil Spills Due to Groundings From >300 GRT Non-Tank Vessels In US Waters (1985-2000)

Year	Vessel Name	Vessel Type	Estimated Bunkers[1]	Gallons Spilled	% Bunkers Spilled[2]
1985	American Legion	Freight Ship	546,996	80,000	14.63%
1991	Vitoria	Freight Ship	628,561	1	0.0002%
1993	Theodore C	Freight Ship	1,119,513	20	0.002%
1994	Nieuw Amsterdam	Passenger	203,373	260	0.13%
1994	Starward	Passenger	191,930	100	0.05%
1995	Northern Wind	Freight Ship	163,821	20,000	12.21%
1995	Star Princess	Passenger	n/a	50	--
1995	Star Princess	Passenger	n/a	25	--
1996	Cape Chalmers	Freight Ship	369,359	1	0.0003%
1997	Kuroshima	Fish Freighter	222,068	47,000	21.16%
1997	Bobo	Freight Ship	629,388	40,000	6.36%
1999	Redfin	Freight Ship	n/a	200	--
1999	New Carissa	Chip carrier	967,675	70,000	7.23%

[1]Bunker capacity estimation based on 70% full bunker tanks and estimation of bunker capacity from formula in Figure 16 and conversion of 294 gallons/tonne.
[2]Based on 70% full bunker tanks.

The probability of different-sized spills was derived from this data as shown in Figure 17. Again, spills of less than 1,000 gallons (assumed to be soft groundings) were eliminated. The spill sizes and probabilities for different sized cargo vessels are shown in Table 19.

Figure 17

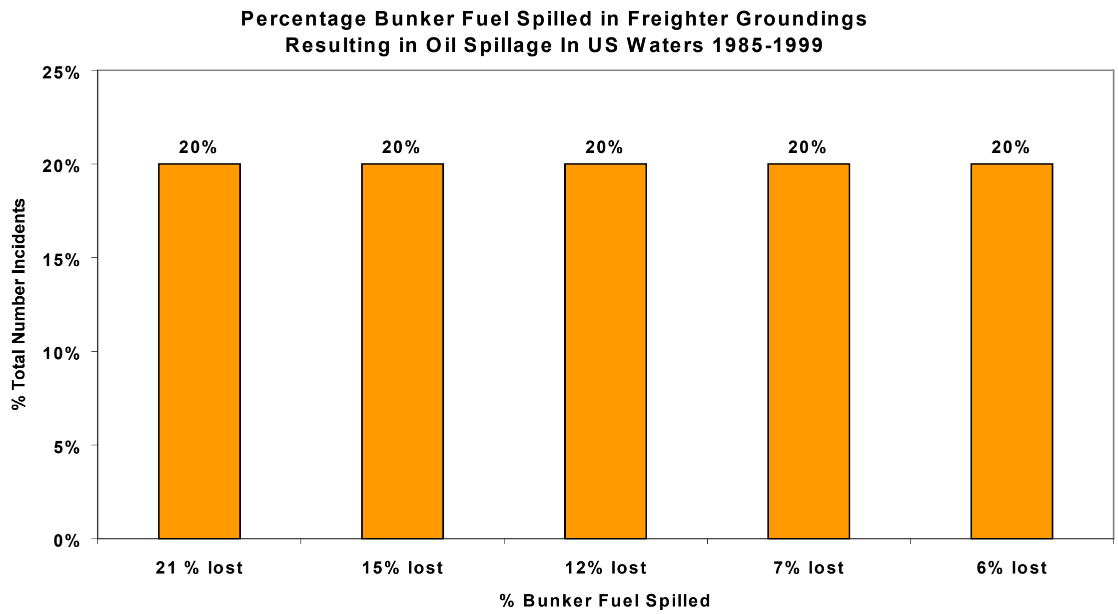


Table 19: Spill Sizes For Freighter Groundings in San Francisco Bay							
% Bunker Loss[1]	**Freighter Bunker Capacity[2]**						**Probability of Loss This Size if Spill Occurs[1]**
	500,000 gal	**730,000 gal**	**920,000 gal**	**1,180,000 gal**	**1,350,000 gal**	**1,500,000 gal**	
21%	107,100	153,300	193,200	247,800	283,500	315,000	**10%**
13.4%	68,340	97,820	123,280	158,120	180,900	201,000	**20%**
6.8%	34,680	49,640	62,560	80,240	91,800	102,000	**20%**
0.1%	510	730	920	1,180	1,350	1,500	**20%**
0.002%	10	15	18	24	27	30	**10%**
0.0002%	1	1	2	2	3	3	**20%**
Annual Transits[3]	2	9	77	97	369	15	**569 total transits**

[1]Based on analysis of 1980-1999 tanker groundings in US waters
[2]Assuming 70% full bunker tanks
[3]Based on San Francisco Bay USCG VTS Operations data August 2000-July 2001

From these data, the expected cumulative probability distributions of spills from non-tank cargo vessels were derived the methodology described in Section 2.1. This distribution is shown in Figure 18. The 20th percentile, 50th percentile, and 95th percentile non-tank cargo vessel spills are shown in Table 20.

Figure 18

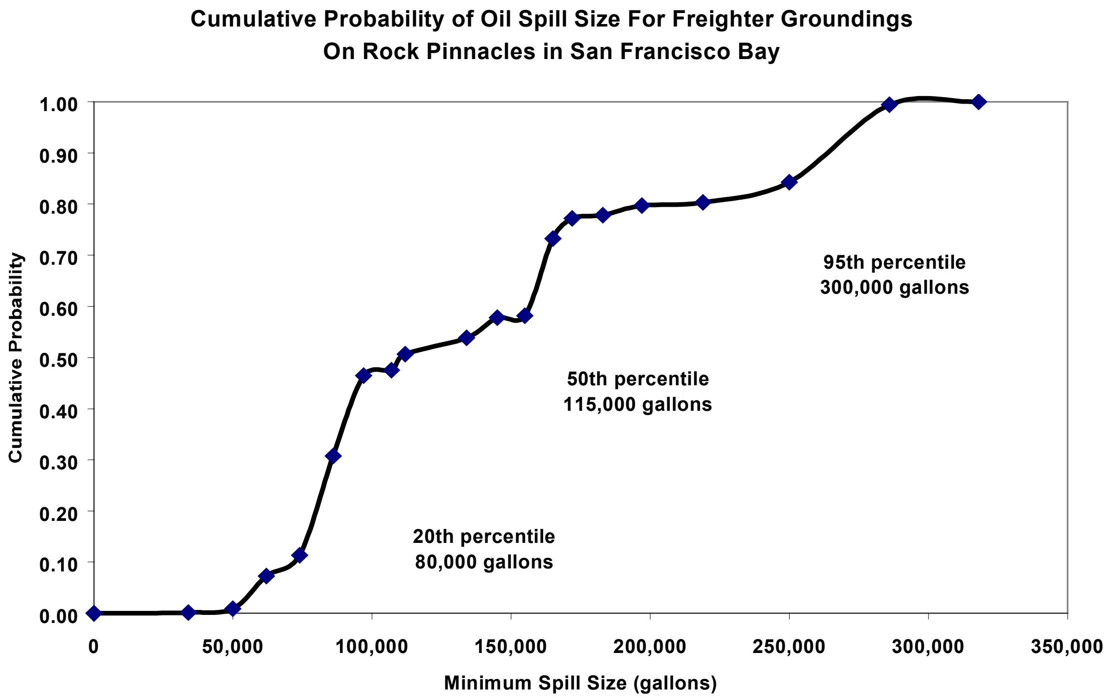


Table 20: Oil Spill Scenarios For Non-Tank Cargo Vessel Groundings On Rock Pinnacles In San Francisco Bay Based on US Data			
Cargo Vessel	20th Percentile	50th Percentile	95th Percentile
	80,000 gallons	115,000 gallons	300,000 gallons

2.4.2 Freighter Spill Scenario Analysis Using International Data

The spill size analysis was repeated using international data sets. Again, as with the tanker analysis, spills of less than 1,000 gallons were eliminated from the data set. As with the international tanker analysis, the very largest spill incidents for freighter groundings were examined in greater detail. There were three large freighter spills – M/V Southern Venture, M/V Aster, and M/V Green Lily – found to be drift groundings in storms. Another incident – M/V Seki Rolette – was found to have spilled nearly half of the total outflow during salvage operations after the initial grounding. These incidents were eliminated from the analysis as they represented unlikely scenarios for San Francisco Bay. Oil spills from freighter groundings in the international data set are shown in Table 21. Results of the spill size analyses are shown in Table 22 and Figures 19-20.

Table 21: % Bunker Fuel Spilled in Oil Spills Due To Groundings From >300 GRT Non-Tank Vessels (International Data)[1]						
Year	Vessel Name	DWT	Bunker Capacity t)[1]	Bunker Capacity (gal)[2]	Amount Spilled (gal)	% Bunkers Spilled
1985	American Legion	2,138	1,968	546,996	80,000	14.63%
1988	Korean Star	30,900	2,421	619,650	180,516	29.13%
1988	Bilkur	5,918	824	210,921	59,000	27.97%
1991	Sanko Harvest	30,000	2,363	656,911	206,000	31.36%
1991	Argo Carrier	15,291	1,452	371,701	1,000	0.27%
1991	Antares	9,793	774	198,034	3,528	1.78%
1992	Seki Rolette*	12,097	1,219	338,829	220,000	64.93%
1992	Arisan	135,748	9,121	2,535,734	44,000	1.74%
1992	Mirna M.	2,634	627	160,394	1,000	0.62%
1993	Scan Lifter	1,433	537	149,362	15,000	10.04%
1993	Rhino	3,175	649	180,312	12,000	6.66%
1993	Nord Hope	17,000	1,532	425,940	153,000	35.92%
1994	Wellborn	28,000	2,235	621,377	26,460	4.26%
1994	Levant Neva	8,340	999	255,655	1,500	0.59%
1995	Northern Wind	1,745	589	163,821	20,000	12.21%
1995	Golf Star	3,050	641	178,091	13,000	7.30%
1995	Oihonna	20,203	1,737	482,848	41,000	8.49%
1995	Iron Baron	37,557	2,846	791,176	95,550	12.08%
1995	Marquesa	70,312	2,041	567,454	37,000	6.52%
1996	Tonyo	7,000	893	248,271	35,403	14.26%
1996	Tonggon Ae Guk Ho	11,525	1,182	328,666	44,000	13.39%
1996	Fu Kuo Hsin No. 2	12,000	1,213	337,106	59,000	17.50%
1996	Romashka	12,432	1,240	344,781	117,600	34.11%
1996	Zheng Dong	19,000	1,660	461,474	44,100	9.56%
1996	Ning Hai	25,667	2,086	579,927	117,600	20.28%
1996	Million Hope	26,847	2,161	600,892	176,000	29.29%
1996	Southern Venture*	44,821	1,190	330,820	206,000	62.27%
1997	Kuroshima	4,845	799	222,068	47,000	21.16%
1997	Bobo	26,523	2,264	629,388	40,000	6.36%
1997	Aster*	3,080	643	178,624	117,600	65.84%
1997	Hälsingland	4,334	723	200,904	59,000	29.37%
1997	Green Lily*	4,348	724	201,153	106,575	52.98%
1997	Jutha Jessica	13,579	1,314	365,160	118,000	32.31%
1997	Capetan Tzannis	14,938	1,400	389,305	35,000	8.99%
1997	North Islands	15,136	1,413	392,823	65,000	16.55%
1998	Marianne	2,415	600	166,809	12,000	7.19%
1998	Amanah	5,119	773	214,851	10,000	4.65%
1998	New Baron	7,098	899	250,012	115,000	46.00%
1998	Chun II	4,665	759	194,301	1,900	0.98%

Table 21: % Bunker Fuel Spilled in Oil Spills Due To Groundings From >300 GRT Non-Tank Vessels (International Data) (continued)						
Year	Vessel Name	DWT	Bunker Capacity (t)[1]	Bunker Capacity (gal)[2]	Amount Spilled (gal)	% Bunkers Spilled
1998	Sunny Glory	1,600	559	143,131	3,963	2.77%
1999	New Carissa	44,527	3,481	967,675	70,000	7.23%
1999	Hedlo	1,924	569	158,085	11,346	7.18%
1999	Sea Hope	3,050	641	178,091	25,426	14.28%
1999	Chios Fighter	15,932	1,464	406,965	67,000	16.46%
2000	Yong Fa	6,271	846	235,319	10,000	4.25%
2000	Nordland	9,054	1,576	438,045	32,340	7.38%
2000	John R.	25,000	2,043	568,076	117,600	20.70%
2000	NOL Schedar	73,048	5,114	1,421,744	15,059	1.06%
2000	River Princess	112,833	7,657	2,128,603	11,760	0.55%
2000	Coral Bulker	25,000	2,085	533,791	1,000	0.19%
2000	Dolphin	64,583	2,334	597,394	1,612	0.27%
2000	Lagik	2,554	621	159,058	8,976	5.64%
2001	Amorgos	65,105	4,607	1,280,621	355,740	27.78%
2001	Patriarche	1,040	523	133,782	1,000	0.75%
2001	Grietje	9,360	1,065	272,684	7,560	2.77%

Source: Environmental Research Consulting Databases
[1]Starred spills involve drift grounding. Seki Rolette spilled 100,000 gal during salvage.
[2]Assumes 70% bunker capacity.

Figure 19

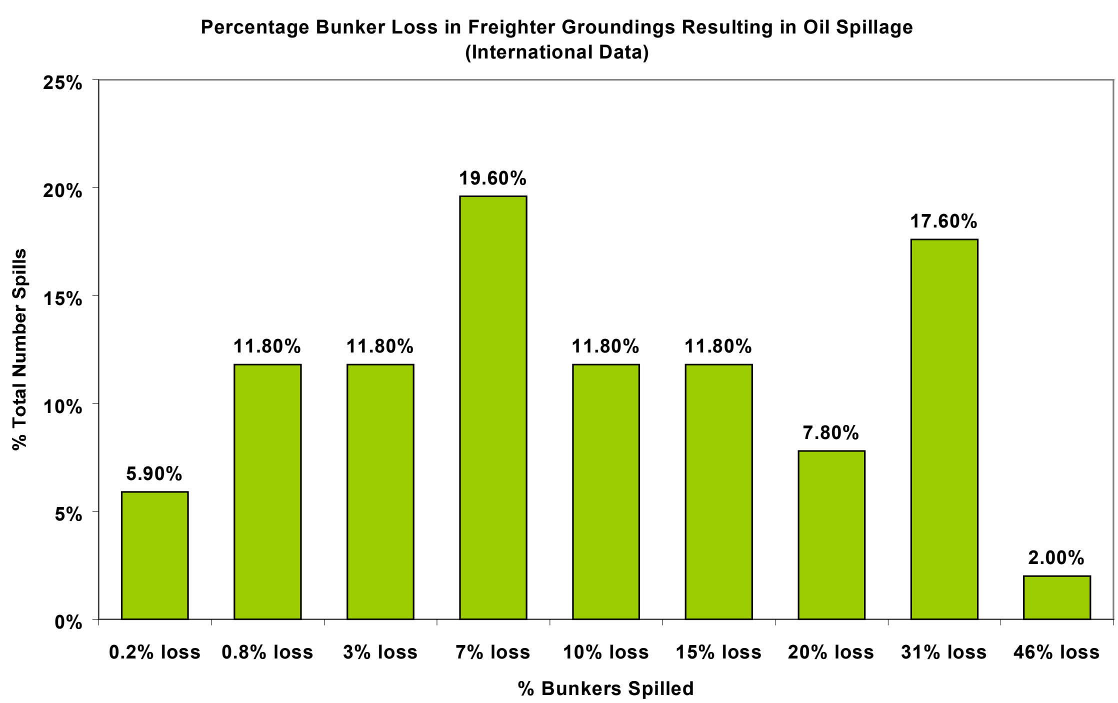


Figure 20

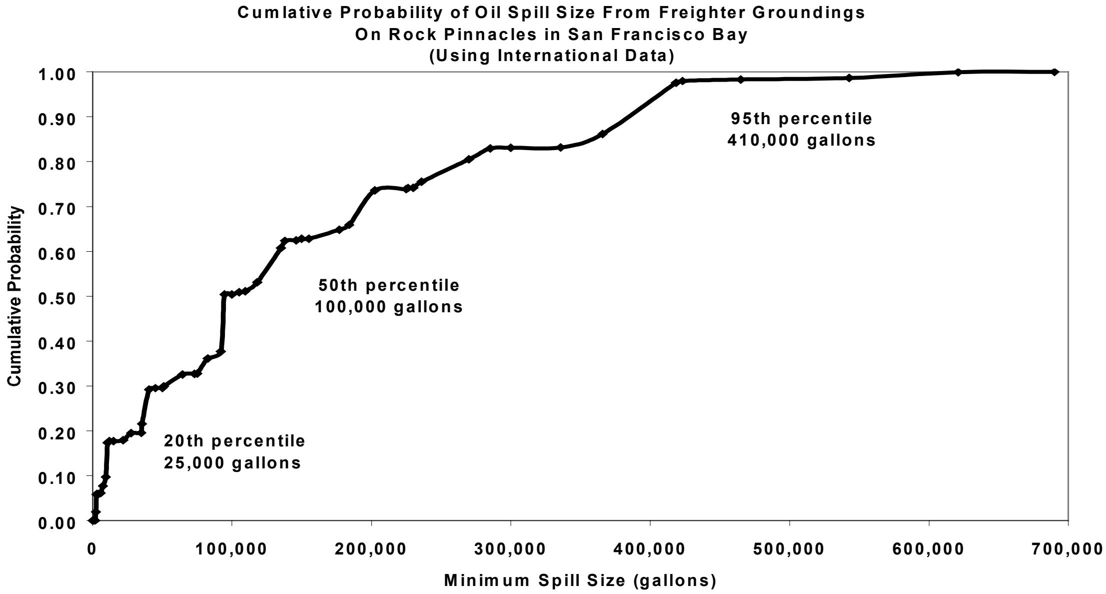


Table 22: Spill Sizes For Freighter Groundings in San Francisco Bay (Using International Data)

% Bunker Loss[1]	Freighter Bunker Capacity[2]						Probability Loss This Size if Spill Occurs[1]
	500,000 gal	730,000 gal	920,000 gal	1.18 million gal	1.35 million gal	1.5 million gal	
46% loss	230,000	335,800	423,200	542,800	621,000	690,000	**2.0%**
31% loss	155,000	226,300	285,200	365,800	418,500	465,000	**17.6%**
20% loss	100,000	146,000	184,000	236,000	270,000	300,000	**7.8%**
15% loss	75,000	109,500	138,000	177,000	202,500	225,000	**11.8%**
10% loss	50,000	73,000	92,000	118,000	135,000	150,000	**11.8%**
7% loss	35,000	51,100	64,400	82,600	94,500	105,000	**19.6%**
3% loss	15,000	21,900	27,600	35,400	40,500	45,000	**11.8%**
0.8% loss	4,000	5,840	7,360	9,440	10,800	12,000	**11.8%**
0.2% loss	1,000	1,460	1,840	2,360	2,700	3,000	**5.9%**
Annual Number Transits[3]	**2**	**9**	**77**	**97**	**369**	**15**	**569 total transits**

[1]Based on analysis of 1980-1999 tanker groundings in international waters
[2]Assuming 70% full bunker tanks
[3]Based on San Francisco Bay USCG VTS Operations vessel traffic dataAugust 2000-July 2001

The final results for the three analyses for freighter grounding spill volumes – from US data only, from international data minus the incidents involving drift groundings in storms and the incident in which outflow occurred during the salvage operations – are shown in Table 23.

Table 23: Comparative Volumes for Oil Spill Scenarios For Freighter Groundings On Rock Pinnacles In San Francisco Bay			
Vessel	**20^{th} Percentile**	**50^{th} Percentile**	**95^{th} Percentile**
Freighter ***US Data***	80,000 gallons	115,000 gallons	300,000 gallons
Freighter ***International Data***	25,000 gallons	100,000 gallons	410,000 gallons

There is currently no legislation analogous to the tanker double-hull mandates of OPA 90 or MARPOL 73/78 on bunker tank configurations for which one could predict reductions in future freighter bunker spill sizes. Although not required by MARPOL 73/78 or OPA 90, there is a trend towards double-hulling of bunker tanks, especially on tankers. However, recent studies on the impact of locating bunker tanks in protective locations (Michel and Winslow 2000), indicate that the principal advantage of double-hulling bunker tanks is in reducing the number of spills, whereas significant reductions in spill size are not expected. Therefore, spill sizes obtained from the historical data on freighter casualties are directly applied without corrections.

2.5 Selection of Freighter Fuel For Spill Scenarios

Most diesel-powered ships burn heavy fuel oil (HFO), whereas steamships typically burn heavier residuals such as Bunker C. Nearly all international flag freighters employ diesel propulsion. Although a significant number of US-flag containerships are powered by steam, most of these vessels are more than 25 years of age. Replacement vessels will likely be diesel-powered. Therefore, heavy fuel oil was selected as the fuel for freighters.

3.0 Verification Exercise

The spill size probability functions are based on *actual* spill data. In order to establish the validity of using actual spill data to develop spill size probability functions as opposed to theoretical functions, a verification exercise was conducted on one of the data analyses (based on US data). The historical spill data were non-dimensionalized by dividing each spill size by the cargo oil or bunkers onboard. This was then applied against the carrying capacity and number of vessels that transit into San Francisco Bay.

National data of spills in San Francisco Bay occur too infrequently to provide a meaningful basis. Even the national data for groundings of tankers and freighters are sparse. There were only 13 tanker and 4 freighter spills over 1000 gallons from groundings in US waters since 1985.

Therefore, for verification purposes, probability density functions representing the non-dimensionalized spill data were developed. When developing the probability density functions, a histogram was plotted showing the number of spills at each 1% increment in size range. The dashed line represents a piece-wise linear fit to the data. This is a probability density function, with the area under the curve equal to 1.0. Due to the sparse data available, it was necessary to apply some discretion when fitting the data. For instance, there were no spills between 3% and 13% of the quantity onboard, although there is no logical reason this should be the case. Therefore, the data from 2% to 16% was averaged and a homogeneous distribution assumed through this spill range.

The functions in Figures 21 and 22 were also applied to the vessel carrying capacity and number of transits. Spill size estimates obtained with this approach were comparable to those obtained when directly applying the historical data.

Figure 21

Probability Distribution Function (Non-Dimensionalized Spill Size) For Tankers

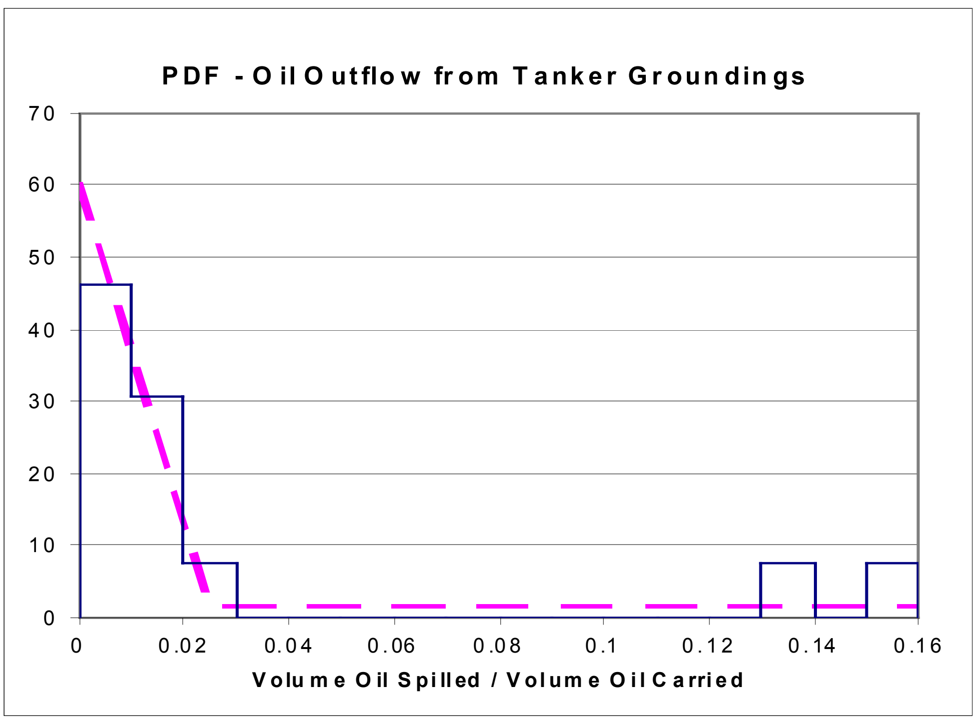
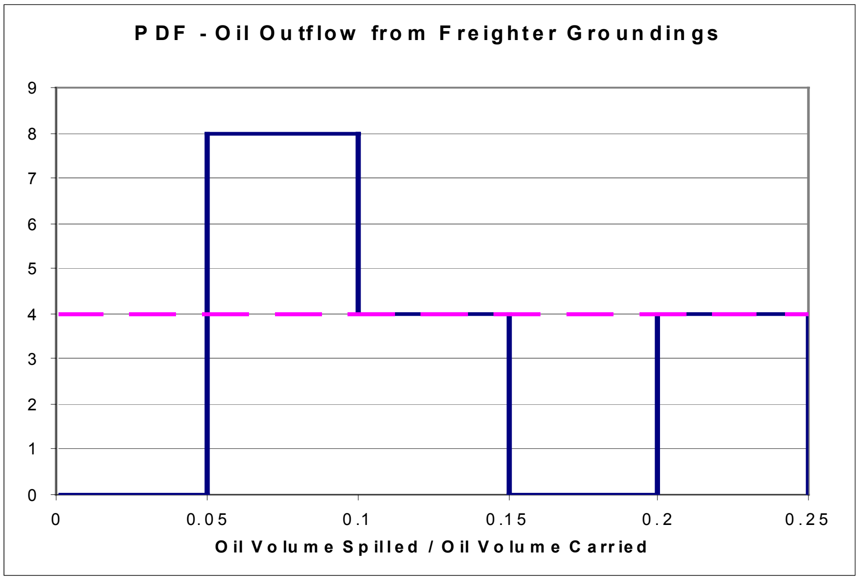


Figure 22
Probability Distribution Function (Non-Dimensionalized Spill Size) For Freighters



4.0 Oil Spill Scenarios For Bio-Economic Modeling

Spill sizes for bio-economic modeling of the 20th, 50th, and 95th percentile oil spills from product tankers, crude tankers, and freighters due to grounding on the rock pinnacles in San Francisco Bay were developed by modeling both US and international data. Since the US data set was relatively small, the results based on the international data set were used to model the impacts of future vessel designs. Based on studies on double hull tankers, the 95th percentile spill volumes were reduced by one half to reflect the expected spill volumes from groundings that could occur in the coming several years and beyond.

It is recommended that the spill sizes to be used for bio-economic modeling of the 20th, 50th, and 95th percentile oil spills from product tankers, crude tankers, and freighters due to grounding on the rock pinnacles in San Francisco Bay be as shown in Table 24.

Table 24: Recommended Oil Spill Scenarios For Vessel Groundings on Rock Pinnacles In San Francisco Bay

Oil Type	20th Percentile	50th Percentile	95th Percentile
Gasoline (Product Tanker)	50,000 gallons	270,000 gallons	1,250,000 gallons
No. 2 Diesel (Product Tanker)	50,000 gallons	270,000 gallons	1,250,000 gallons
North Slope Crude (Crude Tanker)	100,000 gallons	600,000 gallons	3 million gallons
Heavy Fuel Oil (Freighter)	25,000 gallons	100,000 gallons	410,000 gallons

The volumes presented in Table 24 represent the situation as it would stand *approaching the year 2010*. The reduction in outflow sizes would rapidly approach the lower volumes for the 95th percentile spills over the next several years as the tanker fleets are being converted to double hull tankers according to a more accelerated schedule than originally anticipated. Already, as shown earlier, San Francisco has transits by double hull tankers 65% of the time, which is ahead of the international arena. This percentage will also continue to rise.

These spill volumes are based on an analysis of the most complete set of international oil spill currently available to develop the probability of oil outflows of different sizes in the event of hard groundings, though not on catastrophic drift groundings. The probability of oil outflows for groundings in San Francisco Bay are based on an extrapolation of these spill size probabilities onto the actual vessels that currently transit San Francisco Bay with a draft deep enough to potentially ground on the rock pinnacles in the vicinity of Alcatraz Island. The expected spill volumes from future groundings have been taken into account in terms of the impacts of future tanker and freighter configurations on spill sizes.

5.0 References

Herbert Engineering Corp. and Designers & Planners, 1999. Use of Tugs to Protect Against Oil Spills in the Puget Sound Area. *US Coast Guard Report 9522-001*, November 1999.

International Maritime Organization (IMO), 1995. Interim Guidelines for Approval of Alternative Methods of Design and Construction of Oil Tankers under Regulation 13F(5) of Annex I of MARPOL 73/78. *Resolution MEPC.66(37)*. Adopted September 14, 1995.

Michel, K. and Winslow, T., 2000. Cargo Ship Bunker Tankers: Designing to Mitigate Oil Spills. *SNAME Marine Technology*, October 2000.

Rawson, C., 1998. Assessing the Environmental Performance of Tankers in Accidental Grounding and Collision. *SNAME Transactions*,1998.

US Coast Guard Vessel Traffic Data. Personal communication with US Coast Guard San Francisco Marine Safety Office.